METROPOLITAN DISTRICT COMMISSION

DIVISION OF WATERSHED MANAGEMENT

WATER QUALITY REPORT: 2001

WACHUSETT RESERVOIR AND WATERSHED

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

WACHUSETT RESERVOIR

2001 WATER QUALITY DATA

CHEMICAL, PHYSICAL, BACTERIAL

PARAMETER	REPORTING UNITS
Temperature	degrees Centigrade
Depth	meters
Dissolved Oxygen	mg/L
Conductivity	μmhos/cm
Turbidity	nephelometric units
pH	units
Standard Alkalinity	mg/L as $CaCO_3$
EPA Alkalinity	mg/L as $CaCO_3$
Nitrate-Nitrogen	mg/L
Ammonia-Nitrogen	mg/L
Total Kjeldahl Nitrogen	mg/L
Silica	mg/L
Total Phosphorus	mg/L
Fecal Coliform	colonies/100mL
Total Coliform	colonies/100mL

WACHUSETT RESERVOIR

2001 PHYTOPLANKTON DATA

PARAMETER	**REPORTING UNITS**
Algae Concentration	real Standard Units per mL

WACHUSETT RESERVOIR WATERSHED

2001 TRIBUTARY WATER QUALITY DATA

CHEMICAL, PHYSICAL, BACTERIAL

PARAMETER	REPORTING UNITS
Temperature	degrees Centigrade
Depth	feet
Flow	cubic feet per second
Conductivity	µmhos/cm
pH	units
Nitrate-Nitrogen	mg/L
Ammonia-Nitrogen	mg/L
Total Phosphorus	mg/L
Fecal Coliform	colonies/100mL
Total Coliform	colonies/100mL

WATER QUALITY REPORT: 2001
WACHUSETT RESERVOIR AND WATERSHED

1.0 INTRODUCTION

The Metropolitan District Commission Division of Watershed Management was established by Chapter 372 of the Acts of 1984. The Division was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the Division. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2001 water quality data from the Wachusett watershed. A report summarizing 2001 water quality data from the Quabbin and Ware River watersheds is also available from the Division.

The Surface Water Treatment Rule requires filtration of all surface water supplies unless several criteria are met, including the development and implementation of a detailed watershed protection plan. The Division and the MWRA currently have a joint waiver from the filtration requirement and continue to aggressively manage the watershed in order to maintain this waiver. Water quality sampling and field inspections help identify tributaries with water quality problems, aid in the implementation of the Division's watershed protection plan, and ensure compliance with state and federal water quality criteria for public drinking water supply sources. Bacterial monitoring of the reservoir and its tributaries provide an indication of sanitary quality and help to protect public health. The Division also samples to better understand the responses of the reservoir and its tributaries to a variety of physical, chemical, and biological inputs, and to assess the ecological health of the reservoir and the watershed.

Routine water quality samples were collected from twenty stations on fifteen tributaries and from five stations on the reservoir. Algal populations in the Wachusett Reservoir were monitored weekly at the Cosgrove Intake and quarterly at three additional stations in order to detect increasing concentrations (blooms) and potential taste and odor problems, and to recommend copper sulfate treatment when necessary. Fecal coliform samples were collected from the reservoir surface, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations.

The Pinecroft Area drainage basin is being investigated to evaluate the impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small urbanized subbasin at the headwaters of Gates

Brook prior to sewer construction. Two additional sampling locations were added in 1997, one at an agricultural operation and one in a pristine forested watershed, enabling the Division to compare and contrast urbanized conditions with those from agricultural and pristine sites.

Weekly sampling of the Pinecroft neighborhood continued in 2001 following the installation of sewers. Weekly samples were also collected from the agricultural and pristine sampling stations when flow was present. Data collected as part of this study are included in this report. A complete analysis will be published separately after a few more years of data collection and interpretation.

Environmental Quality staff continued to monitor site-specific impacts of development on water quality. Ongoing communications with state and local officials helped ensure implementation of best management practices, remediation of existing problems, and quick notification of imminent threats. Staff attended conservation commission and board of health meetings monthly to provide technical assistance and to gain advance knowledge of proposed activities.

In an effort to refine the process of threat assessment within the Wachusett watershed, Environmental Quality staff divided the watershed into five sanitary districts with the goal of completing a detailed assessment of one district per year on a five-year rotating basis. Information was gathered on hydrology, natural resources, demographics, land use, historic water quality, and both actual and potential threats for the seventeen subbasins within the Reservoir District (tributaries discharging directly into the reservoir). The information was reviewed and summarized in a district overview during 2001, with detailed information presented in seventeen individual subbasin chapters. Both general and specific recommendations are being developed along with a proposed timeline for actions, and the Reservoir District Environmental Quality Assessment will be published under separate cover early in 2002.

2.0 WATERSHED SAMPLING PROGRAM DESCRIPTION

Wachusett Environmental Quality staff collected routine water quality samples from twenty stations on fifteen tributaries and from five stations on the reservoir during 2001. The stations are described below in Table 1 and are located on Figure 1. Fewer stations were sampled than in previous years, but it was felt that sufficient data had been collected previously to allow for a reduction in sampling stations. The reduction in stations also allowed for the addition of total coliform as a routine parameter to be analyzed weekly at all tributary stations. Additional stations were sampled intermittently to support special studies or potential enforcement actions. Nearly 7,000 samples were analyzed in-house; approximately 6,000 bacteria samples, 260 algae samples, and 450 chemical samples. Almost 2,000 physiochemical measurements were done in the field. In addition, more than 1000 samples were collected and sent to the MWRA Deer Island laboratory for the analysis of nutrients.

Each tributary station was visited weekly throughout the year. Temperature and conductivity were measured in the field using a Corning CD-30 conductivity meter and samples were collected for total and fecal coliform analysis. All analyses were done at the MDC lab facility in John Augustus Hall in West Boylston. Monthly samples for nitrate-nitrogen, nitrite-nitrogen, ammonia, silica, total phosphorus, UV-254, total suspended solids, and total organic carbon were collected from eleven stations and analyzed by the MWRA. Depth measurements were done at these stations to calculate flow using previously established rating curves. All sample collections and analyses were conducted according to Standard Methods for the Examination of Water and Wastewater 20th Ed. (Table 2).

Monthly temperature, dissolved oxygen, pH, and conductivity profiles were taken at three reservoir stations (Station 3417/Basin North, Station 3412/Basin South, and Thomas Basin) using a Hydrolab Surveyor III. Quarterly samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, silica, alkalinity, and total phosphorus were collected at the same three stations plus the Cosgrove Intake from the epilimnion, metalimnion, and hypolimnion during thermal stratification and at two depths (surface and bottom) during isothermal conditions. All parameters were analyzed by the MWRA Lab at Deer Island.

Total and fecal coliform samples were collected daily (Monday - Thursday) from the surface at the Cosgrove Intake and from the Route 12 Bridge at Thomas Basin to ensure compliance with federal regulations and to help monitor the effect of weather conditions, tributary inputs, and migratory gull and geese populations on bacteria concentrations. Samples were collected seven days per week at the Cosgrove Intake during the first half of January when bird numbers were elevated and the reservoir had not yet frozen over. Total and fecal coliform samples were also collected monthly or biweekly at numerous locations on the reservoir surface, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations. A sampling grid established eight years earlier with twenty-three sampling locations based on reservoir configuration and flow paths was again utilized. Sample locations are indicated on Figure 2.

TABLE 1

2001 WACHUSETT SAMPLING STATIONS

STATION	LOCATION	FREQUENCY
1. Boylston Brook	Route 70, Boylston	W
2. Cook Brook (Wyoming)	Wyoming Street, Holden	W, M
3. French Brook (70)	Route 70, Boylston	W, M
4. Gates Brook (1)	Gate 25, W.Boylston	W, M
5. Gates Brook (2)	Route 140, W.Boylston	W
6. Gates Brook (3)	Worcester Street, W.Boylston	W
7. Gates Brook (4)	Pierce Street, W.Boylston	W
8. Gates Brook (6)	Lombard Avenue, W.Boylston	W
9. Gates Brook (9)	Woodland Street, W.Boylston	W
10. Jordan Farm Brook	Route 68, Rutland	W, M
11. Hastings Cove Brook	Route 70, Boylston	W
12. Malagasco Brook	West Temple Street, Boylston	W, M
13. Malden Brook	Thomas Street, W.Boylston	W, M
14. Muddy Brook	Route 140, W.Boylston	W, M
15. Quabbin Aqueduct	below circular dam, W.Boylston	W
16. Quinapoxet River (dam)	above circular dam, W.Boylston	W, M
17. Rocky Brook (East Branch)	Rowley Hill Road, Sterling	W, M
18. Stillwater River (sb)	Muddy Pond Road, Sterling	W, M
19. Waushacum Brook (Pr)	Prescott Street, W.Boylston	W
20. West Boylston Brook	Gate 25, W.Boylston	W, M
A. 3409 (Reservoir)	Cosgrove Intake	D, W, Q
B. 3417 (Reservoir)	mid reservoir by Cunningham Ledge	M, Q
C. 3412 (Reservoir)	mid reservoir southwest of narrows	M, Q
D. TB (Reservoir)	Thomas Basin	M, Q
E. Route 12 Bridge	north side of Route 12 (Thomas Basin)	D

D = daily (bacteria M-Th)
W = weekly (bacteria, temperature, conductivity [tribs] and algae [Cosgrove])
M = monthly (nutrients [tributaries], profiles [reservoir])
Q = quarterly (algae and nutrients [reservoir])

Figure 1.

SAMPLING STATIONS

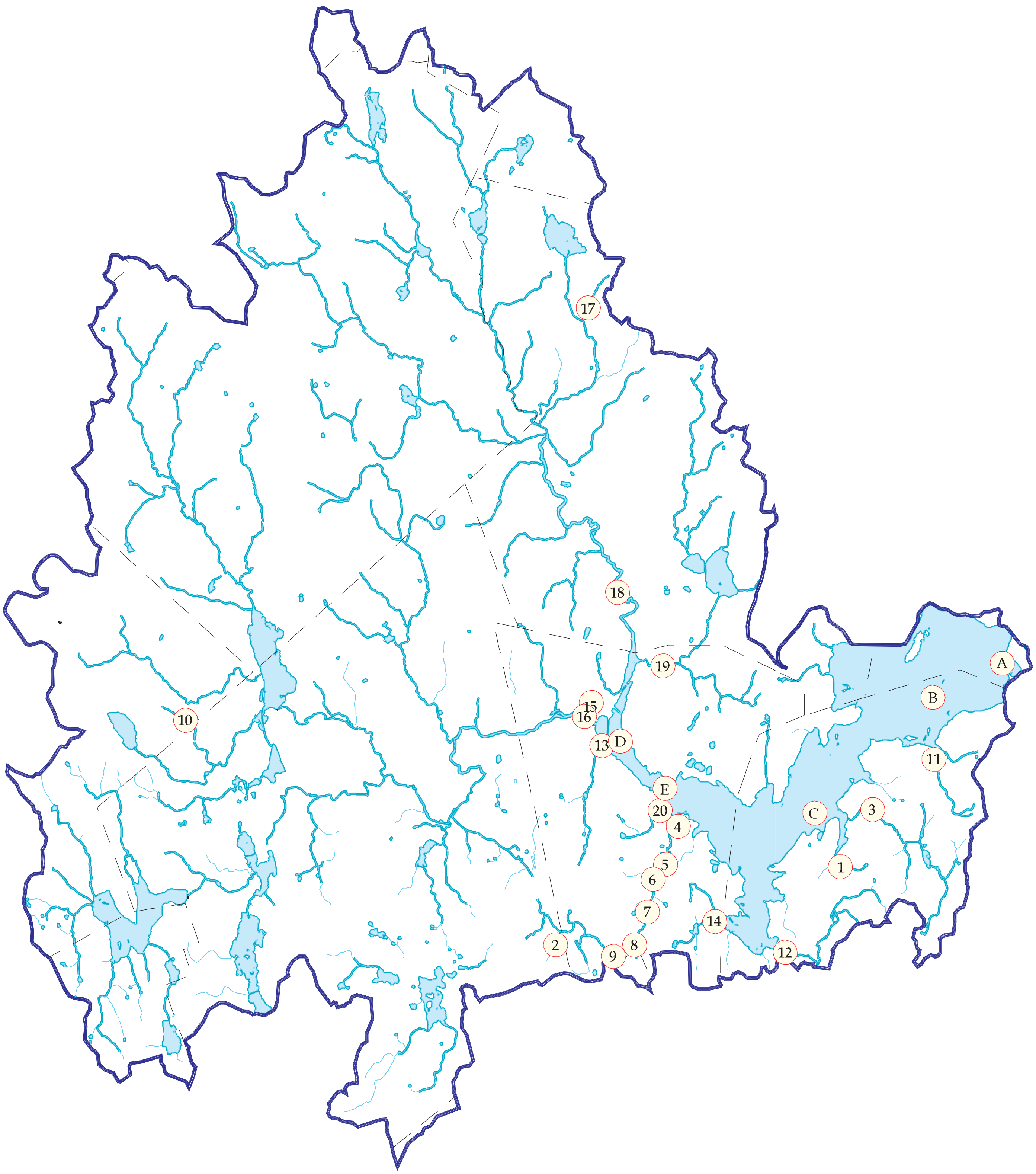


Figure 2.

RESERVOIR TRANSECT STATIONS

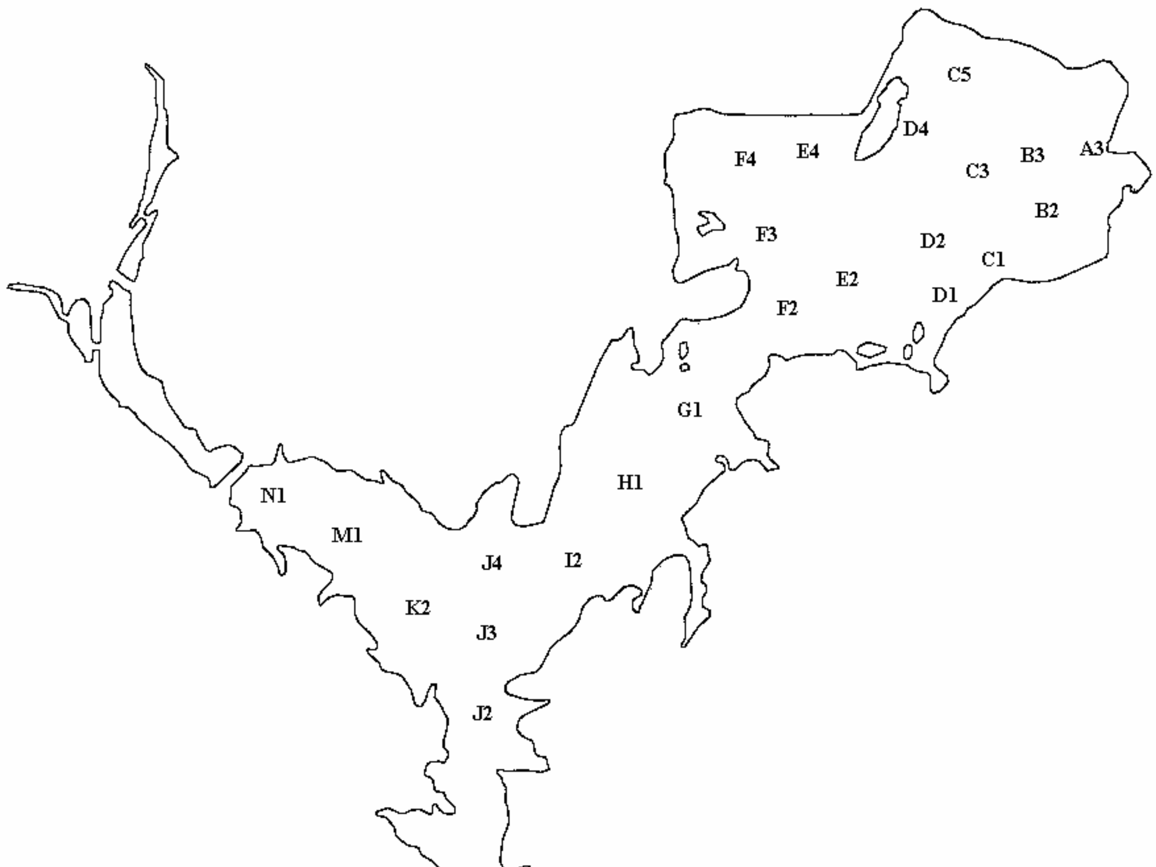


TABLE 2

METHODS USED FOR FIELD AND LABORATORY ANALYSIS
WACHUSETT LABORATORY

PARAMETER	STANDARD METHOD
pH	Hydrolab Surveyor III
Conductivity	YSI Model 30 meter Hydrolab Surveyor III
Temperature	Hydrolab Surveyor III YSI Model 30 meter
Dissolved Oxygen	Hydrolab Surveyor III
Total Coliform	SM 9222 B
Fecal Coliform	SM 9222 D
Algae	SM 10200 F

SM = Standard Methods for the Examination of Water and Wastewater - 20th edition, 1999

Algal populations in the Wachusett Reservoir were monitored at the Cosgrove Intake to detect increasing levels (blooms) and potential taste and odor problems, and to recommend copper sulfate treatment when necessary. Samples were collected weekly at six depths (0, 6, 8, 10, 12, and 14m) to help detect rapidly changing populations of golden-brown algae and other potential problem genera. Samples were collected quarterly from three additional stations to help improve the Division's understanding of algal population dynamics throughout the entire reservoir.

Macroinvertebrate samples were collected from twenty-three stations to supplement physical and chemical measurements with bioassessment protocols. Ten additional samples were collected from five of the same streams in July and October to document any seasonal differences in the macroinvertebrate community. Analysis of the thirty-three macroinvertebrate samples collected in 2001 will take place during 2002.

3.0 SUMMARY AND DISCUSSION OF RESULTS

3.1 TRIBUTARIES

All data collected were recorded in permanent laboratory books and also as part of an electronic database (Microsoft Excel files tribs-01.xls, Algae01.xls, and Nutrients01.xls) located at the MDC-DWM Water Quality Laboratory in West Boylston, Massachusetts. Results of tributary water quality testing are discussed by parameter in sections 3.1.1 - 3.1.5. All water quality data are included as appendices to this report.

3.1.1 BACTERIA

Total and fecal coliform were measured in the tributaries as an indicator of sanitary quality. Coliform density has been established as a significant measure of the degree of pollution and has been used as a basis of standards for bacteriological quality of water supplies for some time. Total coliform are defined in Standard Methods for the Examination of Water and Wastewater - 20th edition (1999) as "facultative anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria that develop red colonies with a metallic golden sheen within 24 hours at 35° C on an Endo-type medium containing lactose". Fecal coliform are a subset of total coliform bacteria that produce blue colonies on M-FC media when incubated for 24 hours at 44.5° C. Fecal coliform bacteria are found within the digestive system of warm-blooded animals and are almost always present in water containing pathogens. Both groups of bacteria are relatively easy to isolate in a laboratory, and direct counts can be made using membrane filtration. The presence of any coliform bacteria in drinking water suggests that there may be disease-causing agents in the water.

Total and fecal coliform levels were measured weekly at all tributary stations. The Massachusetts Class A surface water quality standards established in 314 CMR 4.00 state that "fecal coliform bacteria shall not exceed an arithmetic mean of 20 colonies per 100 mL in any representative set of samples, nor shall more than 10% of the samples exceed 100 colonies per 100 mL". Using a yearly arithmetic mean, the standard of 20 colonies per 100 mL was exceeded at 19 of 20 tributary stations (95%). Only the Quabbin Aqueduct had an annual average of less than the standard. This appears much worse than in previous years, but sampling in 2001 focused primarily on tributaries flowing directly into the reservoir and did not include any of the smaller streams in undeveloped portions of the watershed. It should also be noted that one or two high values can markedly elevate the annual mean of a relatively small data set, and fecal coliform values sometimes increase by several orders of magnitude following storm events or during periods of high groundwater. It is clear that a different way of looking at the data may give a better representation of actual conditions in these tributaries throughout the year. The use of median values as an alternative method to represent water quality was proposed several years ago by Environmental Quality staff. Table 3 includes both annual mean and annual median values for fecal coliform data in the tributaries.

TABLE 3

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN (2001)	MEDIAN (2000)	SAMPLES
Boylston Brook	270	<10	37	10	19	32
Cook Bk. (Wyoming)	20000	<10	662	50	18	40
French Brook (70)	930	<10	69	<10	10	37
Gates Brook (1)	1330	<10	89	20	25	52
Gates Brook (2)	1600	<10	156*	50	43	52
Gates Brook (3)	3800	<10	187	30*	50	52
Gates Brook (4)	6200	<10	331	60	46	52
Gates Brook (6)	8900	<10	575	115	60	52
Gates Brook (9)	2000	<10	131	20	35	52
Hastings Cove Brook	1680	<10	88	<10	5	35
Jordan Farm Brook	350	<10	55*	25	6	24
Malagasco Brook	1100	<10	110	20	26	52
Malden Brook	530	<10	61	20	10	52
Muddy Brook	540	<10	37	10	9	52
Quabbin Aqueduct	0	0	0	0	0	38
Quinapoxet River (dam)	1000	<10	91	20	16	52
Rocky Bk. (E. Branch)	910	<10	47	<10	0	22
Stillwater River (sb)	900	<10	95	25	17	52
Waushacum Brook (Pr)	730	<10	43	10*	20	52
West Boylston Brook	1420	<10	170	50	40	52

*below historic levels

Samples collected at 16 of 20 sampling stations (80%) exceeded the standard of 100 colonies/100 mL on more than 10% of the sampling dates in 2001. This was also a decline from the previous year. Two stations recorded their lowest ever annual mean, however, while two others recorded median values below historic levels (see Table 3). It should be noted that the summer and fall of 2001 were extremely dry and many of the tributaries had reduced flows or went completely dry. Low flows and concentration of contaminants can result in elevated fecal coliform concentrations, and the absence of flow during the late fall and winter when bacteria levels are generally lower can also raise annual values.

When the tributaries are ranked using annual mean values, Cook Brook (Wyoming), West Boylston Brook, and five stations on Gates Brook have the highest concentrations of fecal coliform, followed by Malagasco Brook. When they are ranked using median values, most of the eight worst remain the same, but Jordan Farm Brook and the Stillwater River replace Malagasco Brook and the station at the headwaters of Gates Brook among the eight worst.

Median fecal coliform concentrations in 2001 were similar to those measured in 2000. Four stations (Boylston, Waushacum, Gates 3, and Gates 9) showed some improvement, while three others (Jordan Farm, Gates 4, and Gates 6) had slightly higher median concentrations than in 2000. All but Waushacum Brook and Gates 3 were still well within the range of annual median values recorded over the last fourteen years. It should be noted that only 8 of 20 stations (40%) recorded annual median fecal coliform concentrations of more than 20 colonies per 100 mL. Nine of these same stations had annual median values that exceeded 20 colonies per 100 mL in 2000.

Massachusetts Class A surface water quality standards do not currently address total coliform bacteria, but staff have historically used 100 colonies per 100 mL as a general guideline to indicate whether or not a tributary or the reservoir is seriously contaminated. The presence of only a single coliform colony in a finished drinking water sample is indicative of a problem. The EPA has established a legal limit that states no more than five percent of monthly drinking water samples from a water system can contain coliform. Source water containing less than 100 total coliform colonies per 100 mL should not contain any coliform following standard treatment procedures or filtration. Using a yearly arithmetic mean, the Division's standard of 100 colonies per 100 mL was exceeded at 19 of 20 tributary stations, however (see Table 4). As with the fecal coliform data, only the Quabbin Aqueduct had an annual average of less than the standard. Extremely high concentrations were recorded following storm events during low flow conditions, and mean values of these relatively small data sets were dramatically impacted by these samples. The use of median values as an alternative method to represent water quality has been considered by Environmental Quality staff. Table 4 includes both annual mean and annual median values for fecal coliform data in the tributaries.

If annual median total coliform values are used, then only 15 of 20 stations exceed the standard of 100 total coliform colonies per 100 mL. This is still a greater percentage of tributaries than those exceeding the fecal coliform standard when annual median values are used, and considerably more than is desirable. Total coliform appears to be much more prevalent in the Wachusett tributaries than previously believed, especially in developed subbasins and following storm events. Additional sampling will be done in 2002 to help further the Division's understanding of total coliform bacteria in the Wachusett watershed.

TABLE 4

TOTAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN	SAMPLES
Boylston Brook	7000	<10	845	40	32
Cook Bk. (Wyoming)	110,000	<10	3914	300	39
French Brook (70)	13,800	<10	749	30	37
Gates Brook (1)	10,400	<10	779	240	51
Gates Brook (2)	38,000	10	2416	400	51
Gates Brook (3)	59,000	20	2578	335	51
Gates Brook (4)	69,000	10	4490	410	51
Gates Brook (6)	76,000	<10	6217	800	50
Gates Brook (9)	10,000	<10	763	190	51
Hastings Cove Brook	3200	<10	535	40	35
Jordan Farm Brook	4800	<10	538	185	24
Malagasco Brook	12,500	<10	1002	150	52
Malden Brook	3700	<10	486	200	52
Muddy Brook	3200	<10	421	185	52
Quabbin Aqueduct	160	0	12	3	38
Quinapoxet River (dam)	4800	<10	596	255	52
Rocky Bk. (E. Branch)	1060	<10	144	25	22
Stillwater River (sb)	3700	<10	537	270	52
Waushacum Brook (Pr)	1000	<10	232	120	51
West Boylston Brook	11,300	<10	1425	310	51

Multiple sampling stations on Gates Brook were examined to help locate sources or suspected sources of fecal contamination. Gates Brook remains one of the most contaminated tributaries in the watershed, regardless of whether mean or median values are used. The results from the six stations were variable, although it was very clear in 2001 that conditions at Gates 6 were worse than at the other stations. Gates 6 had the highest annual mean and median values for both total and fecal coliform. Samples collected from Gates 6 had the highest fecal coliform count from this tributary on 22 of 51 days, and had the highest total coliform count on 19 of the 50 days sampled. Mean and median values for both total and fecal coliform samples collected from Gates 4 were worse than all but Gates 6, although Gates 2 actually had the highest fecal coliform value more often than Gates 4. The maximum values recorded were 8900 fecal coliform and 76,000 total coliform colonies per 100mL, both from Gates 6 in September following a rain event of 1.2 inches.

Although annual statistics are useful in determining trends in water quality, it has become clear that they also miss a great deal of information and in fact can provide a misleading assessment of overall water quality. Problems with relying on annual mean coliform numbers have been illustrated throughout this section. While annual median values are a better representation of what has occurred during the year, it appears that a closer examination of the raw data is warranted. The 2001 sampling program intended to address seasonal differences by comparing dry weather samples without including samples impacted by storm events. A separate stormwater sampling program including all routinely sampled tributaries was to be part of the regular sampling program in order to help quantify bacterial loading to the reservoir from storm events. Tributary sampling was to take place immediately following rain events (first flush) and then all stations were to be resampled after 24 and 48 hours to see how long elevated fecal coliform concentrations persist after a storm. Precipitation amounts, groundwater levels, and stream flows were to be carefully documented and compared to bacteria numbers in an attempt to further refine our understanding of the causes of elevated coliform levels in Wachusett tributaries. Unfortunately we were unable to conduct stormwater sampling due to unusually dry weather and staffing limitations.

The data were examined to determine if seasonal differences were present. Quarterly mean and quarterly median total and fecal coliform concentrations clearly illustrated that conditions were worst during the third quarter (July-September) and best during the first (or occasionally the fourth) quarter. This information is important to consider when comparing tributaries or when assessing long-term trend information, because during years with unusually low flow there might be limited data collected during a season with traditionally poor water quality data. Elevated annual bacteria concentrations in 2001 could easily be due in part to the reduced number of samples collected during the fourth quarter because tributaries were dry or experiencing low flow.

3.1.2 NUTRIENTS

Monthly grab samples for nitrate-nitrogen, nitrite-nitrogen, ammonia, silica, total phosphorus, total suspended solids, total organic carbon, and UV-254 were collected from eleven stations to document nutrient loading to the reservoir. Samples for nitrate-nitrogen, nitrite-nitrogen, and ammonia were filtered in the field using a 1 micron glass fiber Acrodisc and then frozen; samples for total phosphorus were frozen without filtration. Samples for the other parameters were preserved as necessary according to standard methods. Flow measurements were determined each month using staff gages and USGS rating curves. Samples were delivered regularly to the MWRA lab at Deer Island and analyzed using methods with low detection limits. All data collected are included in an appendix to this report and are discussed in the following section.

Nitrate-nitrogen concentrations measured in the eight routine tributaries (excluding the "Pinecroft Study" stations) ranged from 0.021 mg/L NO_3-N to 3.84 mg/L NO_3-N. Nitrate levels have historically been highest in West Boylston Brook and are usually significantly elevated with respect to the other tributaries and the reservoir. This remained true in 2001. The mean annual nitrate-nitrogen concentration in West Boylston Brook was between four and twenty times higher than those measured in all other tributaries with the exception of Gates Brook. Elevated nitrate levels in these two brooks are expected because of the high number of improperly functioning septic systems and the density of development in their subwatersheds.

FIGURE 3

WACHUSETT TRIBUTARIES
NITRATE-NITROGEN CONCENTRATIONS (mg/L)

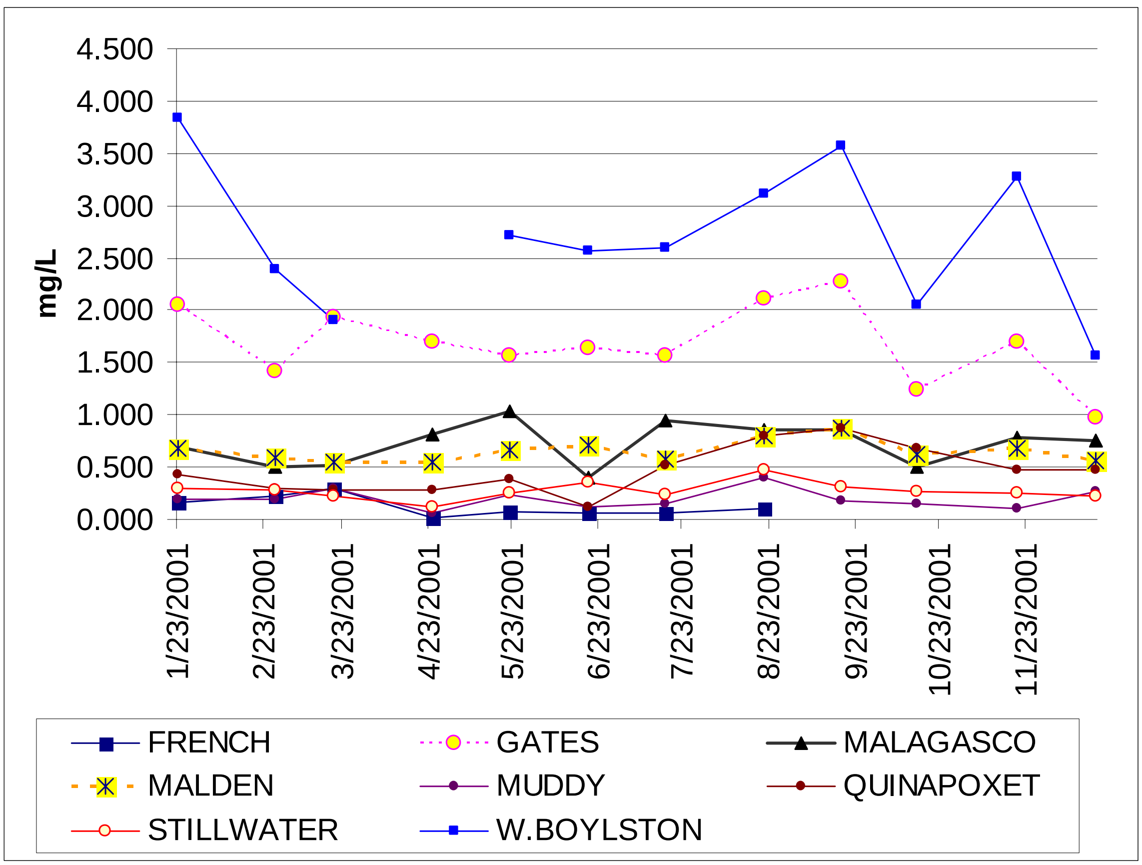


TABLE 5

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.297	1.04	0.391	2.27	3.84	0.865	0.873	0.474
MIN	0.021	0.402	0.057	0.973	1.57	0.541	0.114	0.113
MEAN	0.122	0.721	0.193	1.68	2.69	0.653	0.467	0.273
MED	0.086	0.765	0.180	1.66	2.60	0.646	0.453	0.261

Concentrations were higher at the Cook Brook station than in any other sampled during the year, with a maximum value of 4.59 mg/L NO_3-N. Annual mean and median concentrations were 30-50% higher than those measured in West Boylston Brook. Samples collected from Jordan Farm Brook had concentrations comparable to those seen in West Boylston and Gates Brook samples. Nitrate-nitrogen was detected only at very low concentrations in samples from Rocky Brook (East Branch).

Nitrate data from these three tributaries in the Pinecroft study illustrate significant differences resulting from different land uses (see Table 6). Concentrations were highest in samples from the stream in a high density residential watershed with on-site wastewater treatment (Cook Brook). Annual median values for Cook Brook were 80% higher than those recorded from Jordan Farm Brook, which has a watershed dominated by agricultural landuse. Samples from Rocky Brook (East Branch) contained very low concentrations of nitrate-nitrogen. This tributary is in a forested watershed with almost no development at all.

TABLE 6

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

STATION	COOK (Wyoming)	JORDAN FARM	ROCKY (East)
LANDUSE	[residential]	[agriculture]	[undeveloped]
MAX	4.59	3.00	0.014
MIN	1.98	1.20	<0.005
MEAN	3.55	1.97	0.007
MED	3.86	1.81	0.007

Nitrate-nitrogen concentrations were fairly uniform throughout the year. Some variation was noted in West Boylston and Gates Brooks (see Figure 3) and a steady decline in concentration was observed in Jordan Farm Brook before it dried up in the summer, but the majority of the samples fell within a fairly narrow range. Annual mean and median nitrate-nitrogen concentrations seen in all tributaries during 2001 were comparable to those recorded during 1999 and 2000, although slightly higher in most cases. The exceptions were West Boylston, Jordan Farm, Cook, and Gates Brooks, all of which were slightly lower than last year. Data from all stations fell within historic ranges.

Nitrite-nitrogen was detected at very low concentrations, with a maximum recorded value of 0.015 mg/L measured in May at the Gates Brook station. Most samples, including all samples from Jordan Farm Brook and Rocky Brook (East Branch) had concentrations below the limits of detection (0.005 mg/L). Only 34 of 113 samples (including seven from Gates Brook, six from the Quinapoxet River, and five from West Boylston Brook) contained detectable concentrations of nitrite-nitrogen.

Ammonia was detected at considerably higher concentrations, especially at French and Muddy Brooks. Similar results were noted in 2000. Samples from most tributaries had elevated concentrations in the winter, with midyear increases in West Boylston, French, and Muddy Brooks. West Boylston Brook had a late year increase as well. Beaver may have impacted samples from French Brook, but the persistent presence of elevated concentrations of ammonia in Muddy Brook is as yet unexplained. Almost no ammonia was detected in samples from Cook or Gates Brooks, and none was found in samples from Jordan Farm Brook or Rocky Brook (East Branch).

TABLE 7

AMMONIA-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER	COOK
MAX	0.090	0.039	0.064	0.032	0.091	0.058	0.098	0.048	0.055
MIN	0.008	<0.005	<0.005	<0.005	0.008	<0.005	<0.005	<0.005	<0.005
MEAN	0.042	0.016	0.030	0.007	0.027	0.015	0.028	0.018	0.011
MED	0.033	0.014	0.030	<0.005	0.016	0.005	0.016	0.016	<0.005

Phosphorus is an important nutrient, and has been determined to be the limiting factor controlling algal productivity in the Wachusett Reservoir. EPA Water Quality Criteria (1976) recommended a maximum concentration of 0.05 mg/L total phosphorus in tributary streams in order to prevent accelerated eutrophication of receiving waterbodies. Concentrations measured in the Wachusett tributaries ranged from the detection limit of 0.005 mg/L to 0.273 mg/L total P during 2001. Concentrations were higher than in the previous year, with more than thirty-two percent of all samples collected exceeding the recommended concentration, but all annual mean and median concentrations were within historic norms. Annual mean total phosphorus concentrations were less than 0.05 mg/L in most streams, but were higher in Gates, Malden, and Muddy Brooks. This was quite different than results from 2000, when most of the smaller tributaries had low measured phosphorus values while the two large rivers had elevated readings. The difference may be related to low precipitation and low flows recorded during 2001. Phosphorus in the small streams is concentrated during low flow conditions, resulting in higher measurements, and then might not be reaching the larger rivers further downstream from the sources of this contaminant.

TABLE 8

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.120	0.079	0.273	0.105	0.066	0.137	0.128	0.144
MIN	0.017	0.021	0.014	0.021	0.016	0.016	0.019	0.016
MEAN	0.048	0.037	0.074	0.059	0.032	0.058	0.047	0.044
MED	0.036	0.029	0.034	0.053	0.024	0.045	0.035	0.031

Total phosphorus data from the three Pinecroft tributaries appeare to show significant differences (see Table 9), with mean and median values in Cook Brook (residential) twice those measured in Rocky Brook (undeveloped). Concentrations in Jordan Farm Brook (agriculture) fell between the two. Low flow conditions precluded sampling in the latter two tributaries after July, however, while three additional samples containing elevated levels of total phosphorus were collected from Cook Brook. Even if these samples were excluded from the annual statistics, the relationship between the three tributaries would remain the same.

TABLE 9

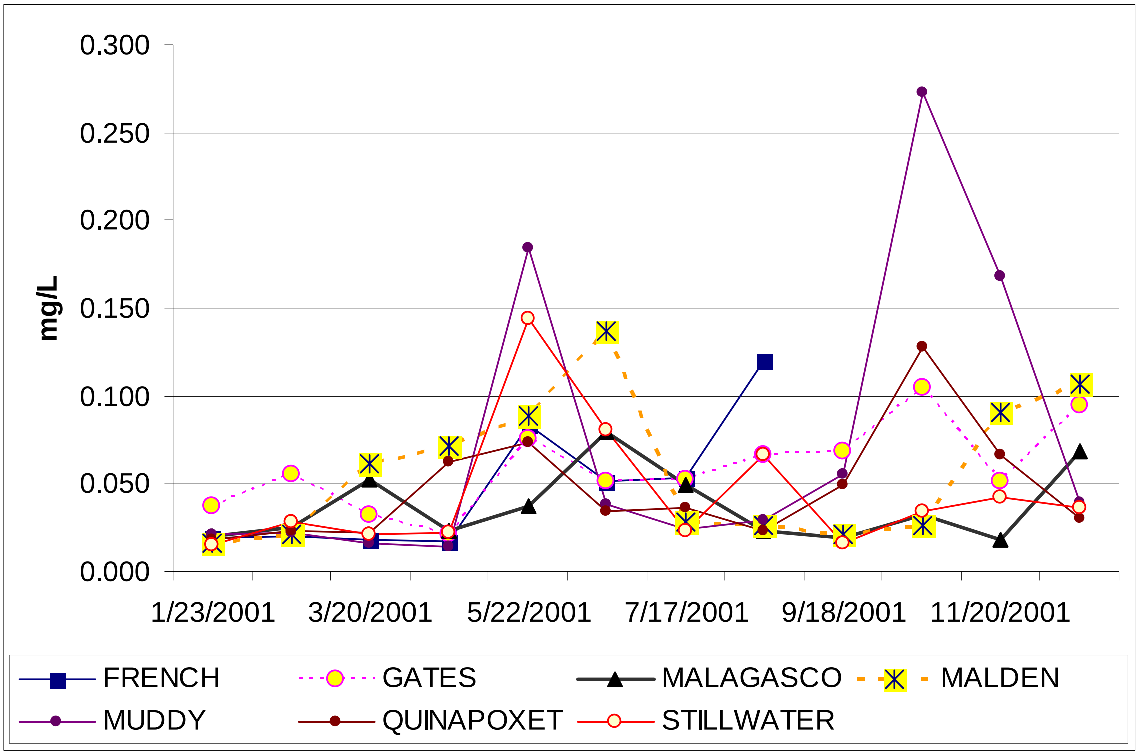
TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

STATION	COOK (Wyoming)	JORDAN FARM	ROCKY (East)
LANDUSE	[residential]	[agriculture]	[undeveloped]
MAX	0.053	0.039	0.039
MIN	0.012	0.011	0.005
MEAN	0.029	0.020	0.016
MED	0.024	0.017	0.011

Total phosphorus concentrations were fairly uniform throughout the year with increases noted during the late spring and again in the fall (see Figure 4). Increases were most pronounced in Muddy Brook. Elevated bacteria concentrations were recorded on the same days that phosphorus concentrations were highest, and in both cases there had been approximately 0.3 inches of rain shortly before the samples were collected, so it is fairly clear that the increases were at least in part due to stormwater contamination. A quantification of impacts from stormwater remains a high priority for the Division.

FIGURE 4

WACHUSETT TRIBUTARIES
TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)



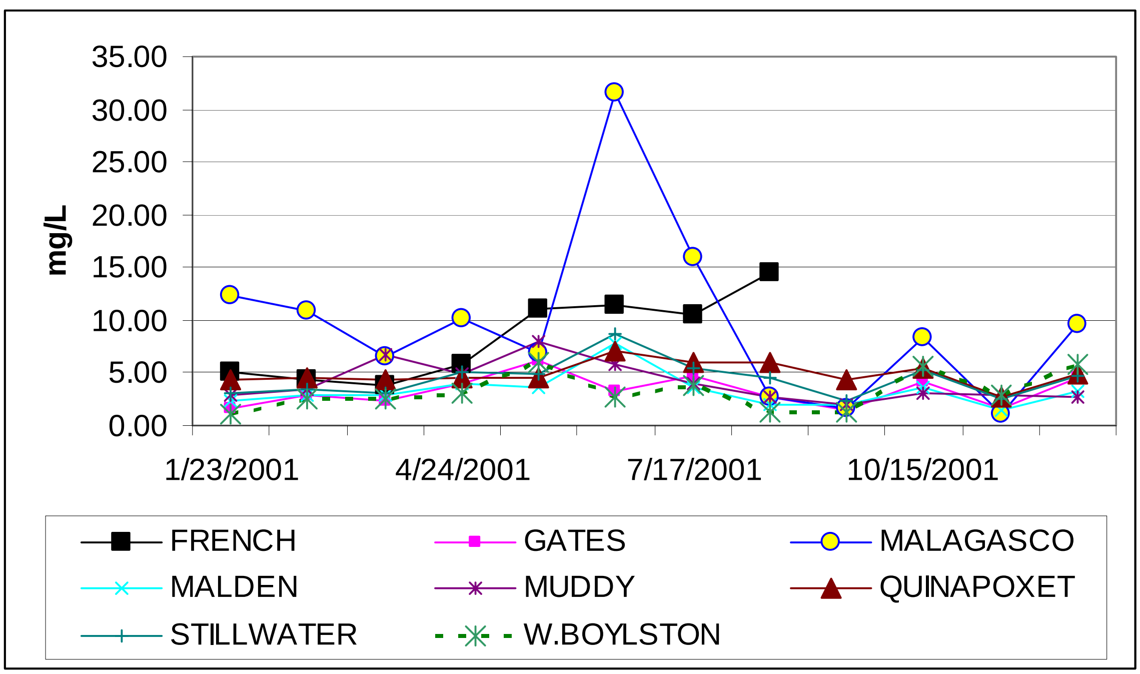
Silica concentrations ranged from a low of 2.81 mg/L (French Brook, 4/24) to a high of 21.7 mg/L (Gates Brook, 5/22). Annual mean concentration in the watershed during 2000 was 9.02 mg/L. Concentrations were remarkably uniform during the year with the exception of two high values from Gates and Malden Brooks in May and June. Malden Brook had the highest annual mean and median concentration, while French Brook had the lowest. Low concentrations were again measured in the Quinapoxet and Stillwater Rivers as well.

Total suspended solids are those particles suspended in a water sample retained by a filter of 2µm pore size. These particles can be naturally occurring or might be the result of human activities. Total suspended solids in the Wachusett tributaries ranged from <1 to 181 mg/L. High suspended solids were measured on several dates in Muddy Brook and on a single occasion each from the Quinapoxet and Stillwater Rivers. West Boylston, Jordan Farm, and Rocky Brooks never had measurements in excess of 5 mg/L.

Total organic carbon (TOC) and UV-254 measure organic constituents in water and are important as a way to predict precursors of harmful disinfection byproducts. TOC in the tributaries ranged from 1.03 to 31.5 mg/L, with an overall mean value of 5.14 and the highest readings from Malagasco and French Brooks. Many of the streams had stable TOC readings throughout the year, although values in French Brook increased steadily through the spring and summer until sampling was discontinued due to low flow conditions. One extreme elevated value was also seen in Malagasco Brook in June. Measurements of UV-254 were comparable to TOC measurements as expected. Organic compounds such as tannins and humic substances absorb UV radiation and there is a correlation between UV absorption and organic carbon content. The highest UV-254 readings were also from Malagasco and French Brooks.

FIGURE 5

WACHUSETT TRIBUTARIES
TOTAL ORGANIC CARBON CONCENTRATIONS (mg/L)



3.1.3 CONDUCTIVITY

Fresh water systems almost always contain small to moderate amounts of mineral salts in solution. Conductivity is a measure of the ability of water to carry an electric current, which is dependent on the concentration and availability of these ions. Elevated conductivity levels are indicative of contamination from stormwater or failing septic systems, or can be the result of watershed soil types.

In order to provide a more accurate assessment of tributary water quality, criteria were proposed by the DWM during the mid 1990s relating conductivity and fecal coliform levels to the likelihood of contamination from failing septic systems. A simple statistical analysis was used to develop a ranking system for tributaries, using percent exceedence of specific criteria. Tributaries with more than fifty percent of the samples exceeding the Class A Standard for fecal coliform of twenty colonies per 100 mL are considered impacted by septic systems. The impact is considered minor if less than eighty percent of samples exceed a conductivity standard of 120 µmhos/cm, moderate if greater than eighty percent of samples exceed the 120 µmhos/cm standard, and severe if more than twenty percent of samples exceed a standard of 360 µmhos/cm. These criteria appear to give a fairly good indication of whether or not a sampling location is impacted by failing septic systems rather than by an alternative source of contamination, although annual flow conditions need to be considered. Stream flow appears to be directly related to conductivity, with "dry" years (low flows) concentrating contaminants during the warm months and elevating mean annual conductivity. Years with less precipitation and lower tributary flow result in higher overall conductivity measurements and appear to increase the number of streams severely impacted. For this reason it is suggested that more than a single year be used in assessing these criteria.

Conductivity was measured weekly at all tributary stations, with values ranging from 32 µmhos/cm (Rocky Brook) to 3861 µmhos/cm (Gates Brook – Worcester Street). Annual mean values ranged from 40 µmhos/cm (Rocky Brook) to 909 µmhos/cm (Gates Brook – Pierce Street). High values were recorded during the late winter and spring in conjunction with snow and ice storms, salt applications, and elevated runoff. Very high readings such as the one from Gates Brook were noted in mid March during a period of significant melting. Except for samples described above, conductivity values in most tributaries were generally highest in the summer, fall, and early winter when flows were lowest. Conductivity in Gates, West Boylston, and Cook Brooks were consistently high throughout the year.

An assessment of conductivity and fecal coliform data from 2001 using the criteria previously described found that only six of twenty stations were likely contaminated by improperly functioning septic systems. All six stations (West Boylston Brook, Cook Brook, and four stations on Gates Brook) were considered severely impaired. This problem has been well documented, and sewers in Holden and West Boylston have been constructed specifically to deal with this issue.

A number of stations were close to meeting the criteria for "likely contaminated", but were just below the percent exceedence of the Class A standard. The Quinapoxet River, Boylston and Malagasco Brooks, and the two remaining stations on Gates Brook had conductivity measurements that would suggest severe impacts. Malden Brook would be moderately impaired, while Jordan Farm Brook and the Stillwater River would have only minor impacts from septic systems. Since bacteria levels were below the criteria, and because conductivity measurements were surely impacted by the lack of rainfall in the latter half of the year, it is not clear that these stations were likely contaminated by septic systems.

A comparison of this assessment with ones done in 1998, 1999, and 2000 seems to indicate improving conditions in the watershed. A lower percentage (30%) of tributaries overall was assessed as likely contaminated by faulty septic systems, down from 33% in 2000, 38% in 1999, and 47% in 1998. This improvement is even more significant since low flow conditions probably elevated conductivity levels due to concentration of minerals in the streams. In addition, many of the smaller tributaries in areas with less development (monitored for the past few years) were not sampled in 2001.

3.1.4 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity, or the measure of a solution's acidity or alkalinity, is expressed as pH on a scale ranging from 0 to 14. Underlying geologic formations, biological processes, and human contaminants impact the pH of a water body. In this region most streams and lakes tend to be relatively acidic (pH less than 7) due to granite bedrock and the impact of acid precipitation originating from the Midwest.

No measurements of pH have been done for the past two years. More than a decade of routine sampling in the tributaries has shown very little variation either seasonally or over time. Historic low values in some tributaries may have been caused by impacts of runoff from acid precipitation, while all other recorded values are considered to be representative of normal background conditions.

3.1.5 *GIARDIA / CRYPTOSPORIDIUM*

Giardia and *Cryptosporidium* samples were not collected by Environmental Quality staff during 2001. Data have been collected from a number of locations over the past several years, but no clear seasonal trends have been determined, and presence or absence appear to be related more to precipitation, flow conditions, and presence of wildlife rather than season. Sampling will continue under the auspices of a UMASS study to help improve our understanding of the presence of these protozoa.

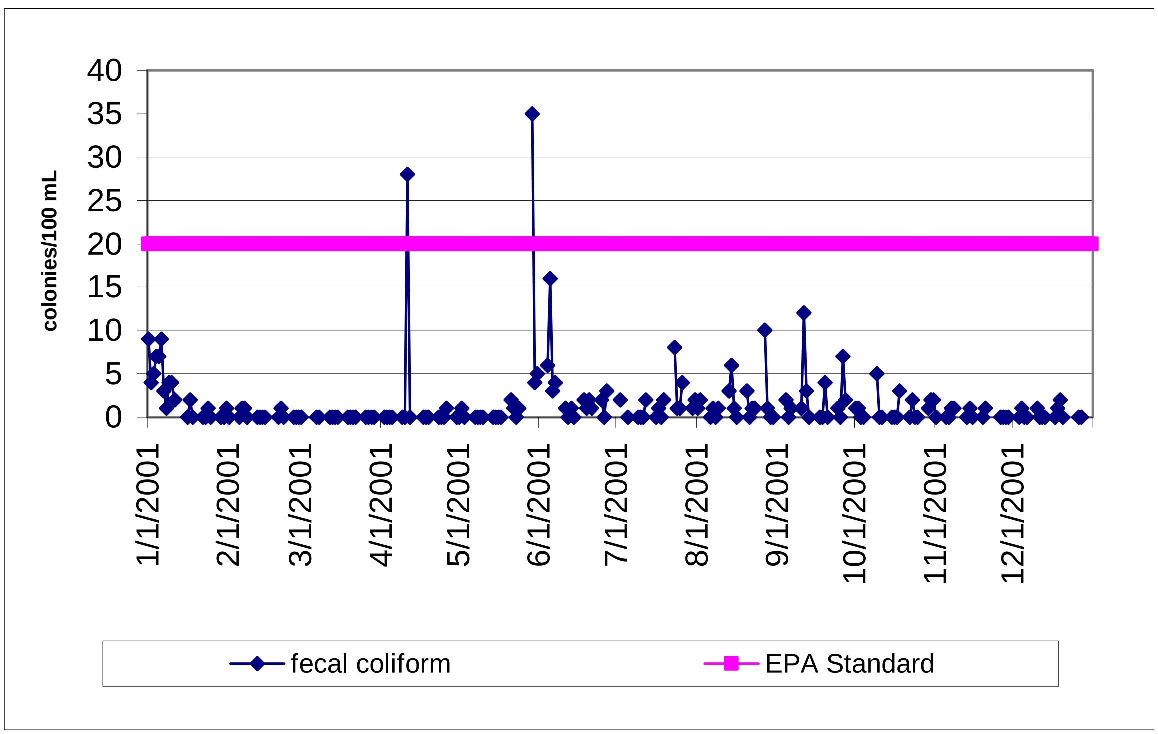
3.2 RESERVOIR

3.2.1 BACTERIA

A total of 195 bacteria samples were collected at the Cosgrove Intake by Environmental Quality staff during 2001. Many were surface samples collected from the back walkway, but a total of 56 during January, February, March, and April were taken from an internal tap when ice formation around the intake structure precluded sampling by the usual method. EPA's fecal coliform criteria for drinking water require that at least ninety percent of all source water samples contain less than 20 colonies per 100 mL. Almost ninety-nine percent of the samples collected at the Cosgrove Intake during 2001 contained less than the standard (Figure 6). The standard was exceeded only twice, on April 11th shortly after ice-out and again on May 29th. Problems caused by roosting gulls and other waterfowl were minimized due to a rigorous harassment program and bacteria levels remained very low during the critical winter months. MWRA official compliance samples are always collected from the internal tap and did not exceed the standard at any time during 2001.

FIGURE 6

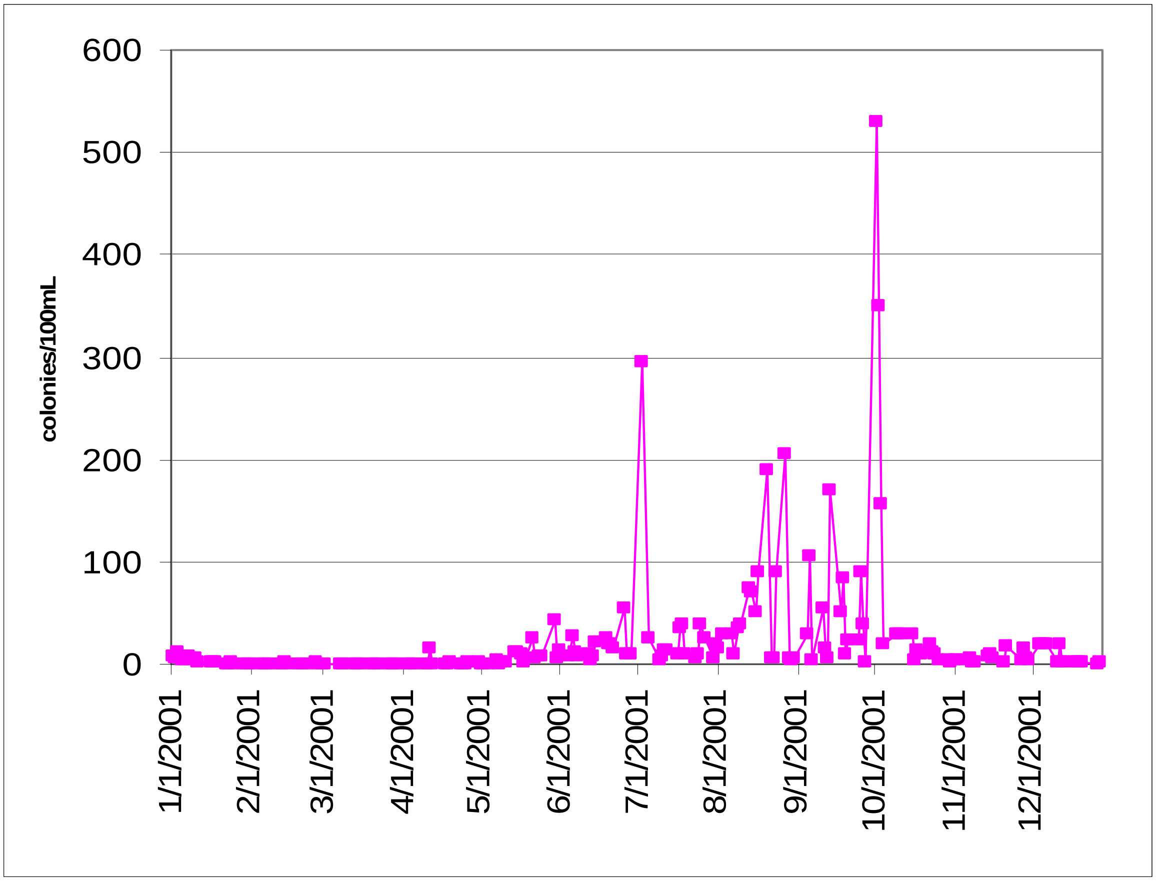
COSGROVE INTAKE
FECAL COLIFORM CONCENTRATIONS (colonies/100mL)



Total coliform was measured in all samples collected from the Cosgrove Intake during 2001. Concentrations were low during much of the year, but were elevated from July through early October. Investigations are ongoing to determine exactly what organism was being measured, as a concurrent rise in fecal coliform concentrations was not seen. Initial results suggest that *Aeromonas* sp. may have been the dominant organism in the reservoir during the summer.

FIGURE 7

COSGROVE INTAKE
TOTAL COLIFORM CONCENTRATIONS (colonies/100mL)



Samples were also collected at twenty-three surface stations across the reservoir and three from 5, 10, and 20 meters deep to document the relationship between seasonal bacteria variations and roosting populations of gulls and geese. Sample locations were illustrated on Figure 2. Samples were collected biweekly or monthly during the year from May 2 through December 27. No samples were collected prior to May due to extensive ice cover. The data are included in Tables 10 and 11 on the following pages.

Figure 10

Wachusett Reservoir Fecal Coliform 2001 Transect Data

	05/02/01	06/06/01	07/12/01	08/22/01	09/10/01	09/26/01	10/10/01	10/24/01	11/14/01	11/28/01	12/12/01	12/27/01
Cosgrove	1	3	2	1	1	7	0	0	1	0	0	0
B-2	1	1	0	0	0	0	0	0	0	1	0	0
B-3	4	11	0	0	2	3	0	1	0	0	0	0
C-1	0	0	0	0	0	3	0	1	0	2	0	1
C-3	0	5	0	1	0	0	1	0	1	1	0	0
C-5	1	3	0	8	1	4	0	2	0	0	0	0
D-1	0	1	0	0	1	2	1	2	2	0	1	1
D-2	1	0	0	37	0	1	1	2	0	0	0	3
D-2 (5m)		0	0	11	0	0	0	0	0	0	0	
D-2 (10m)		2	0	0	0	0	1	1	0	0	0	
D-2 (20m)		0	0	1	1	0	3	5	2	1	0	
D-4	0	4	3	0	1	0	1	0	1	0	3	0
E-2	0	1	11	2	0	1	1	0	2	2	0	0
E-4	0	1	0	0	2	2	0	1	1	1	0	0
F-2	0	0	10	0	1	1	0	1	3	7	2	2
F-3	0	1	0	5	3	5	5	12	1	2	0	0
F-4	0	3	1	1	4	8	0	0	0	0	1	0
G-2	0	0	0	0	0	0	2	0	14	7	2	5
H-2	0	0	0	0	0	6	0	1	8	25	10	8
I-2	0	0	0	6	1	14	1	0	26	14	46	26
J-2	0	0	0	1	1	1	1	1	5	7	2	19
J-3	0	0	2	41	0	0	0	3	37	39	60	152
J-4	0	0	3	1	7	42	20	1	5	35	180	156
K-2	0	0	4	4	5	10	3	53	3	27	33	174
M-1	0	1	15	1	0	150	5	0	0	12	4	5
N-1	1	3	20	0	1	76	3	0	5	1	9	3

Samples collected in May, June, and July contained only small numbers of fecal coliform bacteria at most locations, with slightly elevated levels in July at the southern end of the reservoir where small numbers of birds continued to roost. Monthly samples from August and September contained very low levels of fecal coliform at most stations, with the exception of a single sample near the south roost and a sample from Prescott Cove. A second round of samples collected at the end of September contained elevated levels of fecal coliform at locations throughout the southern end of the reservoir as roosting gulls returned to seasonal concentrations.

Samples collected twice in October contained only small numbers of fecal coliform bacteria at most locations again, with single samples from the southern roost containing elevated levels of fecal coliform. Samples collected biweekly in November and December contained a greater number of fecal coliform (especially in December) and concentrations were elevated at a greater number of locations, reflective of the nightly position of roosting gulls and other waterfowl in the traditional and East roosts. Samples collected at the middle of the reservoir and near the Cosgrove Intake still contained very few fecal coliform bacteria. Fecal coliform concentrations did not exceed 100 colonies/100mL in any sample collected from the reservoir in 2001 other than in five samples from the southern roost area, once in September and from four locations in December. The average of all transect samples collected in 2001 was only six fecal coliform colonies per 100mL.

Total coliform concentrations were similar to fecal coliform concentrations, but some significant differences were noted. Very low concentrations at all sampling stations were measured in May, June, and July, but a sample from Prescott Cove in August contained 600 colonies per 100mL (see Table 11 below). Samples collected in September contained elevated levels of total coliform at almost all locations, with thirteen samples containing 100 or more colonies per 100mL. A maximum value of 1210 colonies per 100mL was measured at the end of the month in a sample collected near the mouth of Gates Cove. This increase in total coliform was also noticed in samples collected from the Cosgrove Intake as well as in samples from the watershed tributaries. Numbers of total coliform declined in October and remained low throughout the remainder of the year, with elevated concentrations observed primarily at the southern end of the reservoir in conjunction with elevated fecal coliform concentrations.

The bird harassment program was very successful in 2001, with markedly fewer gulls, geese, and ducks visiting the north end of the reservoir and significantly lower fecal coliform concentrations in all samples collected. Problems with weather (wind, fog) never had a significant impact on harassment activities, and due to the extreme warm temperatures there was never any ice on the reservoir to hinder harassment activities. In addition it appears that a majority of the birds have adapted their flight patterns to avoid the north end of the reservoir entirely. A detailed summary of the harassment program with associated data is published weekly throughout the harassment season as part of the MWRA Weekly Water Quality Report; a compilation for the entire season will be available on May 1, 2002.

Figure 10

Wachusett Reservoir Total Coliform 2001 Transect Data

B-2	6	1	11	5	140	5	10	8	2	2	1	0
B-3	1	24	7	5	30	20	50	2	8	6	2	0
C-1	0	2	6	40	20	20	40	4	4	6	1	0
C-3	2	11	9	10	20	5	30	2	4	8	1	1
C-5	10	7	24	20	50	90	100	4	10	12	2	2
D-1	0	9	6	20	160	10	10	4	2	4	1	0
D-2	1	5	6	30	40	30	40	8	1	10	1	0
D-2 (5m)	0	7	15	5	50	20	40	6	4	16	1	
D-2 (10m)	1	3	3	5	40	30	20	2	6	6	1	
D-2 (20m)	2	0	10	5	60	20	5	10	8	8	1	
D-4	2	5	5	5	60	5	50	20	18	2	4	0
E-2	0	3	15	10	50	40	30	1	14	16	1	2
E-4	1	2	3	5	100	20	60	4	2	4	1	0
F-2	0	2	5	5	100	10	10	6	16	12	8	1
F-3	0	5	10	10	50	100	10	16	6	6	1	1
F-4	0	4	5	600	30	10	10	1	6	2	1	0
G-2	0	6	4	20	300	590	10	1	16	30	4	5
H-2	0	4	4	5	40	20	40	4	16	34	16	8
I-2	0	2	1	5	230	10	5	12	30	24	46	20
J-2	1	7	8	5	370	10	10	8	14	34	2	10
J-3	0	5	5	80	30	30	10	6	66	48	76	116
J-4	0	3	5	5	460	50	20	8	24	38	226	140
K-2	0	5	5	20	450	250	10	82	18	30	36	172
M-1	0	7	26	5	20	1210	10	2	16	22	12	12
N-1	0	19	37	5	220	890	50	4	10	24	10	4

3.2.2 WATER COLUMN CHARACTERISTICS

Field Procedure

MDC staff routinely measure water column profiles in the Wachusett Reservoir for the following parameters: temperature, dissolved oxygen, percent oxygen saturation, specific conductance, and hydrogen ion activity (pH). Profiles are measured monthly at the three main stations (Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin; see Figure 1) weather and ice conditions permitting.

The frequency of profile measurement is increased to semimonthly or weekly during the summer period of thermal stratification in order to monitor growth conditions for phytoplankton and to track the progress of the Quabbin "interflow" through the Wachusett basin during periods of water transfer (see below). The thermally stratified water column of summer is characterized by a layer of warm, less dense water occupying the top of the water column ("epilimnion"), a stratum with a thermal gradient in the middle ("metalimnion"), and a stratum of cold, dense water at the bottom ("hypolimnion"). Also during the stratification period, profiles are measured at additional locations of interest including the Route 12 Bridge, the Quinapoxet Basin railroad bridge, the Beaman Street Bridge, and the Stillwater Basin railroad bridge. Profiles are measured at one meter intervals, except during periods of isothermy and mixing (generally November through March) when intervals of two or three meters are adequate to characterize the water column.

Water column profiles are measured with a "Reporter" or "H20" multiprobe and "Surveyor 3" water quality logging system manufactured by Hydrolab Corporation (Austin, Texas). This instrument is generally charged and calibrated on the day preceding each field effort and also given a post-measurement calibration check. At the conclusion of field work, data recorded by the logging system is downloaded to a PC and transformed into an Excel spreadsheet.

Station 3417 (Basin North) has been selected for graphically depicting seasonal changes in the water column profile of Wachusett Reservoir because it is representative of the deepest portion of the basin and it is not influenced by turbulence from local water inputs or withdrawals that could disrupt profile characteristics. Profiles measured in Thomas Basin and at Cosgrove Intake (Station 3409) are influenced by inflow from the Quabbin Aqueduct and withdrawal at the Cosgrove Intake respectively.

The Quabbin “Interflow” in Wachusett Reservoir

The transfer of water from Quabbin to Wachusett Reservoir via the Quabbin Aqueduct has a profound influence on the water budget, profile characteristics, and hydrodynamics of the Wachusett Reservoir. During the years 1995 through 1999, the amount of water transferred annually from Quabbin to Wachusett ranged from a volume equivalent to 44 percent of the Wachusett basin up to 90 percent. The period of peak transfer rates generally occurs from June through November. However, at any time of the year, approximately half of the water in the Wachusett basin is derived from Quabbin Reservoir.

The peak transfer period overlaps the period of thermal stratification in Wachusett and Quabbin Reservoirs. Water entering the Quabbin Aqueduct at Shaft 12 is withdrawn from depths of 13 to 23 meters in Quabbin Reservoir. These depths are within the hypolimnion of Quabbin Reservoir where water temperatures range from only 9 to 13 degrees C in the period June through October. This deep withdrawal from Quabbin is colder and denser relative to epilimnetic waters in Wachusett Reservoir. However, due to a slight gain in heat from mixing as it passes through Quinapoxet Basin and Thomas Basin, the transfer water is not as cold and dense as the hypolimnion of Wachusett. Therefore, Quabbin water transferred during the period of thermal stratification flows conformably into the metalimnion of Wachusett where water temperatures and densities coincide.

The term interflow describes this metalimnetic flow path for the Quabbin transfer that generally forms between depths of 7 to 15 meters in the Wachusett water column. The interflow penetrates through the main basin of Wachusett Reservoir (from the Route 12 Bridge to the Cosgrove Intake) in about three to four weeks depending on the timing and intensity of transfer from Quabbin. The interflow essentially connects Quabbin inflow to the Cosgrove Intake in a “short circuit” undergoing minimal mixing with ambient Wachusett Reservoir water.

In 2001, the transfer of water from Quabbin Reservoir was initiated on May 16th. Unlike previous years when average transfer rates typically ranged from 240 to 290 mgd, the 2001 transfer averaged only about 150 mgd during the period of interflow penetration of the main basin. A weak conductivity minimum was not detected in front of the Cosgrove Intake until July 2nd (see Conductivity, Section 3.2.2.3 below) indicating completion of interflow penetration through the main basin. The period of interflow transit of the basin was prolonged to about seven weeks instead of the usual three to four week period characteristic of the higher transfer rates.

In addition to the slower rate of interflow penetration, the interflow stratum formed higher in the water column and was thinner than usual due to the reduced initial transfer rates in 2001. The leading edge of the interflow detected in front of Cosgrove on July 2nd had a thickness of four meters forming between 7 and 11 meters deep.

Communication with the MWRA on July 12th revealed that the characteristic “signature” of interflow water entering the Cosgrove Intake (represented by lower values of UV254 and specific conductance) had still not been detected. This apparent contradiction was resolved when a water column profile was measured off the Cosgrove Intake catwalk on July 18th showing that the lower intake gates were withdrawing water from depths mostly below the nascent interflow stratum (located at 10.5 to 12.5 meters deep). Based on this information, the MWRA switched from the lower intake gates to the upper gates and began intercepting the interflow stratum between 7 and 9 meters deep.

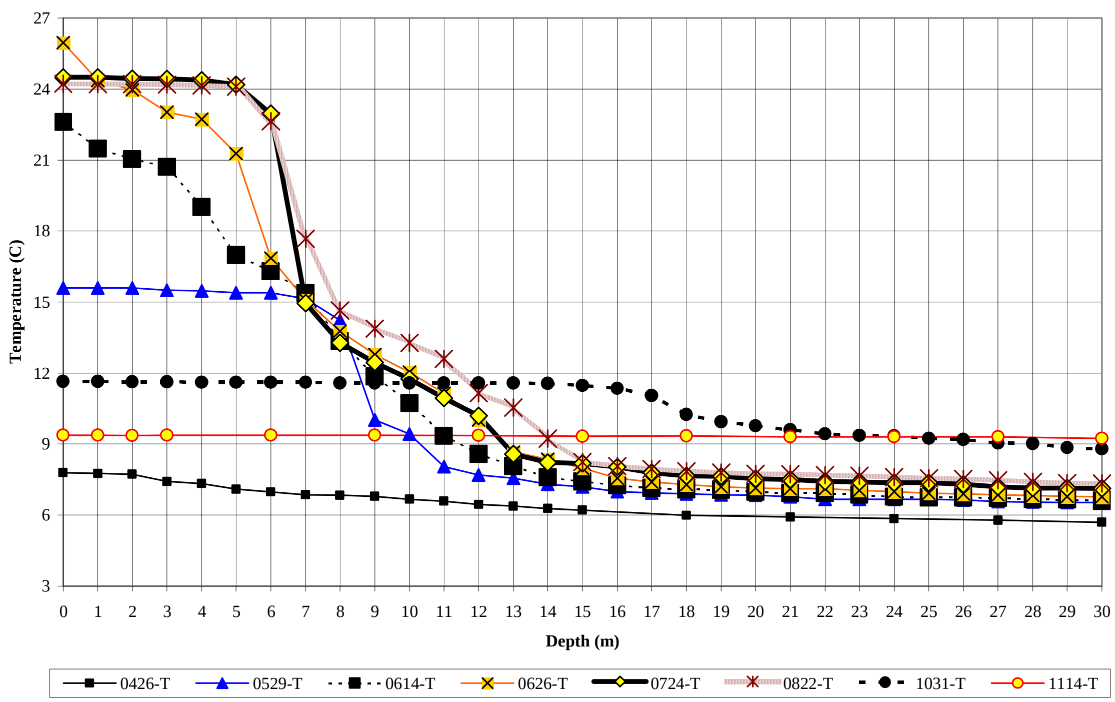
By mid-August, the interflow stratum had eventually developed into a more typical configuration with a thickness of eight meters forming between 6 and 14 meters deep. The influence of the 2001 Quabbin interflow on profile characteristics in Wachusett Reservoir is discussed in the sections that follow.

3.2.2.1 TEMPERATURE

Typical of most deep lakes and reservoirs in the temperate region, Wachusett Reservoir becomes thermally stratified in summer. The development of thermal stratification due to solar radiation and atmospheric warming in spring and summer and the subsequent loss of heat leading to fall turnover at Station 3417 (Basin North) is depicted in Figure 8.

Figure 8

Wachusett Reservoir Temperature Profiles
April - November 2001 at Basin North/Station 3417



The initial stages of thermal stratification were evident on the May 29th measurement date when a difference of approximately nine degrees C existed between the top and bottom of the water column (Figure 8). The top of the water column continued to gain heat and the upper six meters had reached a temperature of approximately 24° C by July 24th. Differences in water density resulting from the thermal gradient caused the typical stratification pattern of epilimnion, metalimnion, and hypolimnion to form in the water column.

The development of the interflow from Quabbin (see Interflow section above) can be seen in the profile measured on July 24th. A very steep thermal gradient exists between depths of six and seven meters in which the temperature dropped approximately eight degrees C. Profiles measured in July and August show a thermocline (defined as a temperature gradient of 1 degrees C per meter or greater) beginning at a depth of 6 meters and falling steeply to temperatures characteristic of the Quabbin interflow. This steep gradient in temperature and density caused by the interflow stabilized the position of the metalimnion between approximately 6 and 14 meters depth.

The presence of the Quabbin interflow was also evident in the temperature profiles as a plateau in the thermocline between 8 and 11 meters where the temperature centers around 13° to 14 ° C (Figure 8). This plateau represents the "core" of the interflow stratum that undergoes minimal mixing with ambient Wachusett water.

Highest temperatures in the epilimnion were recorded in July and August at about 24 ° C while temperatures in the hypolimnion remained at about 7 ° C throughout the summer (Figure 8). This thermal gradient persisted through the end of August. In September, the system began to lose heat as air temperatures cooled.

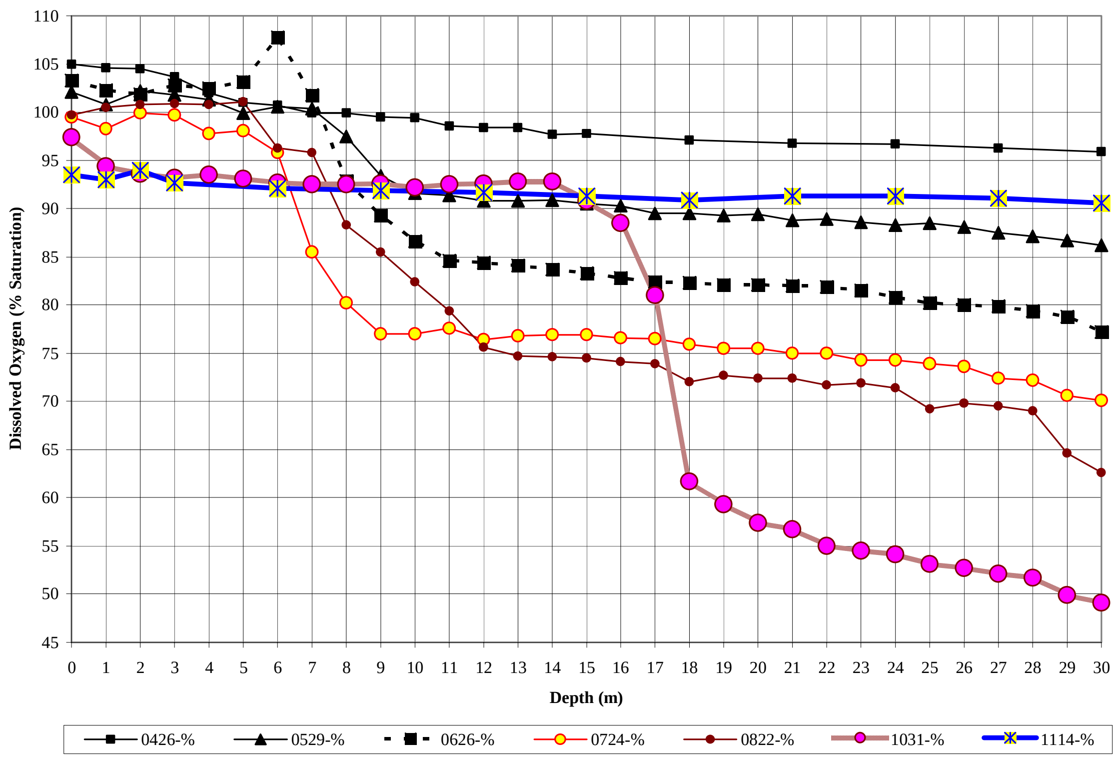
Profiles measured on October 31st show that heat losses and wind energy had caused the water column to be mixed down to a depth of 16 meters thus homogenizing the epilimnion and the metalimnetic Quabbin interflow. A difference of less than 3 ° C existed between the top and bottom of the water column at this time (Figure 8). Soon after the October 31st measurement date, wind energy dispersed the remnant stratification pattern and mixed the entire water column, in an event known as fall "turnover". Profiles recorded on November 14th show the water column to be isothermal at slightly over 9 ° C (Figure 8).

3.2.2.2 DISSOLVED OXYGEN

Measurement of dissolved oxygen profiles throughout most of the year generally show values ranging from 70 to 100 percent saturation for ambient water temperatures. A maximum dissolved oxygen saturation value approaching 108% was observed at the boundary between epilimnion and metalimnion at a depth of 6 meters on the June 26th measurement date (Figure 9). The sharp thermal gradient at this depth in combination with other factors evidently triggered a short period of intense photosynthetic activity by phytoplankton concentrated in this narrow vertical stratum. The release of oxygen associated with this activity resulted in the spike of high saturation values measured on this date.

Figure 9

Wachusett Reservoir Dissolved Oxygen Profiles
April - November 2001 at Basin North/Station 3417



During the period of thermal stratification, demand for oxygen in the hypolimnion reduced oxygen concentrations to as low as 50 percent saturation before fall turnover in early November replenished oxygen throughout the water column. Reductions in oxygen concentration are also evident in the metalimnion during the stratification period, but these are mainly indicative of oxygen demand within the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir. The progressive lowering of dissolved oxygen saturation values in the metalimnion and hypolimnion from April through October at Station 3417 (Basin North) is depicted in Figure 9.

On July 24th, hypolimnetic dissolved oxygen concentrations were at 75 percent saturation except for the very bottom of the water column which was at 70 percent saturation. By August 22nd, hypolimnetic concentrations at most depths had declined into the 70 to 75 percent saturation range with concentrations less than 65 percent recorded near the bottom of the water column (Figure 9). Relatively low saturation values measured near the bottom of the water column indicate slightly higher rates of oxygen demand by microbial decomposition processes occurring at the sediment-water interface.

Hypolimnetic oxygen concentrations in September and October continued to decline gradually into the 50 to 55 percent saturation range. However, absolute dissolved oxygen concentrations remain above 5.8 ppm at all depths throughout the stratification period. Profiles measured on October 31st show that heat losses and wind energy had caused the water column to be mixed down to a depth of 16 meters with a concomitant replenishment of oxygen to greater than 90 percent saturation throughout the mixed volume. Soon after the October 31st measurement date, wind energy dispersed the remnant stratification pattern, mixing and exposing the entire basin volume to the atmosphere and thereby replenishing dissolved oxygen concentrations at all depths. Profiles recorded on November 14th show dissolved oxygen registered between 91 and 94 percent saturation at all depths (Figure 9).

3.2.2.3 CONDUCTIVITY

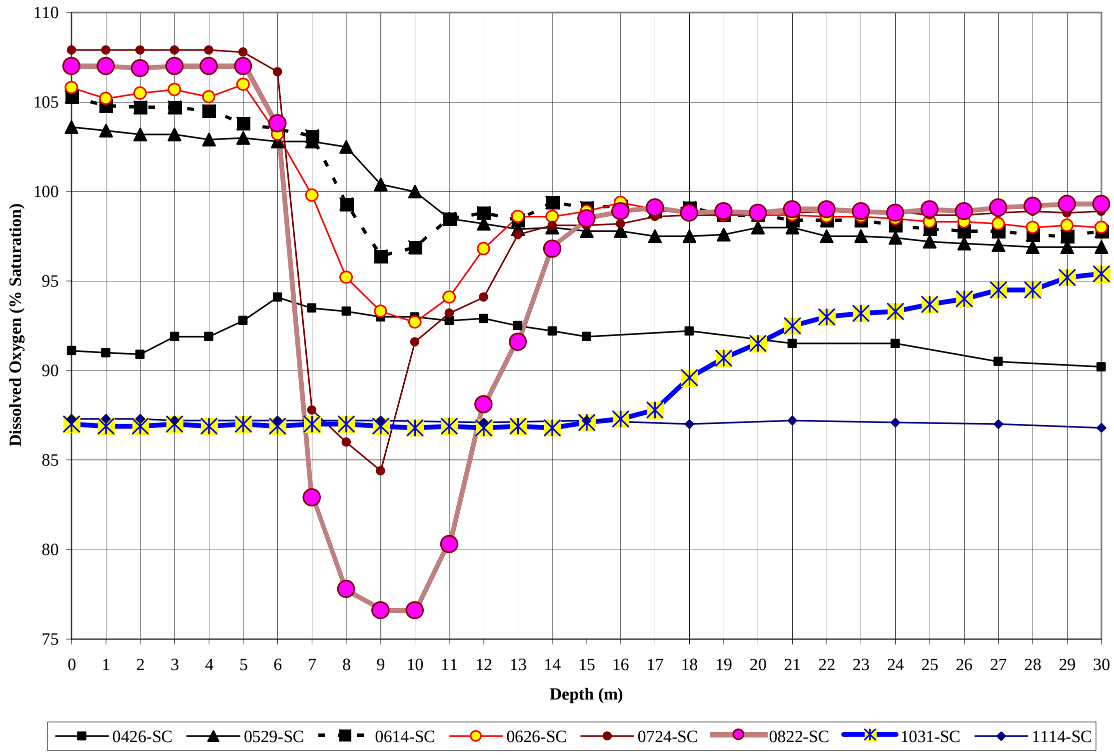
Specific conductance ("conductivity") profiles measured in the Wachusett Reservoir reflect the interplay between native water contributed from the Wachusett watershed and water transferred from the Quabbin Reservoir. The Quinapoxet and Stillwater Rivers are the two main tributaries to Wachusett Reservoir and are estimated to account for approximately 75 percent of annual inflow from the reservoir watershed. Measurements of conductivity in these rivers generally range between 60 and 240 μmhos/cm with an average value between 125 and 150 μmhos/cm. In contrast, the average conductivity value of Quabbin water is approximately 40 μmhos/cm. Typically, during periods of isothermy and mixing (November through March), conductivity values throughout the main Wachusett basin range from 75 to 100 μmhos/cm depending on the amount of water received from Quabbin. During the summer stratification period the Quabbin interflow is conspicuous in profile measurements as a metalimnetic stratum of low conductivity. Figure 10 depicts conductivity profiles measured at Station 3417 (Basin North) from April through November.

On April 26th, before the Quabbin transfer had been initiated, conductivity values ranged from 90 to 94 μmhos/cm throughout the water column. The profiles recorded from June 14th through August 22nd show the development of the interflow stratum as a "trough" in the conductivity profile between depths of 6 and 14 meters (Figure 10). This trough intensifies (extends to lower conductivity values) over the period of transfer as water in the interior of the interflow undergoes less mixing with ambient reservoir water at the boundaries of the interflow stratum. On August 22nd, a minimum interflow conductivity value of 76.6 μmhos/cm was observed at depths of 9 and 10 meters at Station 3417.

Profiles measured on October 31st show that heat losses and wind energy had caused the water column to be mixed down to a depth of 16 meters. The conductivity of the stratum resulting from the homogenization of the epilimnion and metalimnetic Quabbin interflow was approximately 87 μmhos/cm. A slight gradient of increasing conductivity persisted below 16 meters (Figure 10). Soon after the October 31st measurement date, wind energy dispersed the remnant stratification pattern and mixed the entire water column. By November 14th, with the Quabbin transfer continuing to dilute the Wachusett water column, a conductivity value of about 87 μmhos/cm was measured uniformly throughout.

Figure 10

Wachusett Reservoir Conductivity Profiles
April - November 2001 at Basin North/Station 3417



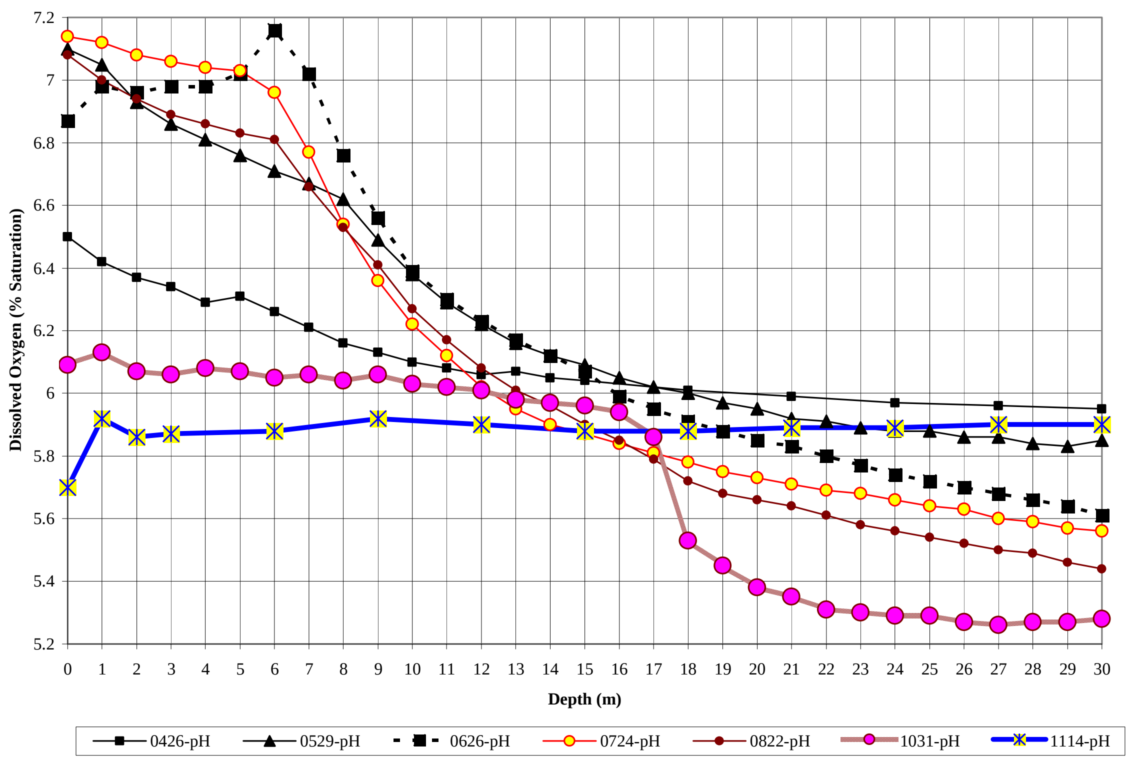
3.2.2.4 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity (pH) in Wachusett Reservoir is determined ultimately by the exchange of inorganic carbon between the atmosphere and water (the carbon dioxide-bicarbonate-carbonate "buffering system"). Specific patterns of pH distribution vertically in the water column and seasonally over the year are mainly determined by the opposing processes of photosynthesis and respiration. Generally, pH values in Wachusett Reservoir range from around neutral (pH=7) to slightly acidic (pH=6). Figure 11 depicts pH profiles measured at Station 3417 (Basin North) from April through November.

Photosynthesis by phytoplankton results in the uptake of carbon dioxide dissolved in the water. The uptake of carbon dioxide tends to increase pH in the epilimnion where photosynthetic activity is greatest. Maximum pH values approaching 7.2 were observed at the boundary between epilimnion and metalimnion at a depth of 6 meters on the June 26th measurement date (Figure 11). As discussed above in relation to the dissolved oxygen maximum, a short period of intense photosynthetic activity by phytoplankton concentrated at this depth was evidently triggered by the sharp thermal gradient in combination with other factors.

Figure 11

Wachusett Reservoir pH Profiles
April - November 2001 at Basin North/Station 3417



Photosynthetic activity maintained epilimnetic pH in the range between 6.8 and 7.2 through August. Values of pH ranging from 6.0 to 6.8 were measured in the metalimnion during the stratification period, but these are mainly indicative of the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir.

In contrast to the utilization of carbon dioxide by photosynthetic organisms, microbial decomposition of organic matter produces carbon dioxide. In the hypolimnion, where microbial respiration is the dominant process, the production of carbon dioxide tends to decrease pH. In June, soon after the establishment of thermal stratification, pH values in the hypolimnion had decreased to values between 5.6 and 6.0. Hypolimnetic pH values continued to decrease to a minimum of around 5.3 by the end of October. Wind energy dispersed the stratification pattern at turnover with resulting pH values of around 5.9 measured uniformly throughout the mixed water column in November (Figure 11).

3.2.2.5 TURBIDITY

The Division no longer measures turbidity values at the Cosgrove Intake weekly since the MWRA records this information continuously. Turbidity values were low throughout the year, well below the EPA's filtration avoidance criteria of 5 NTU.

3.2.3 NUTRIENTS

Sampling for measurement of nutrient concentrations in Wachusett Reservoir has been conducted quarterly since the conclusion of the program of monthly sampling conducted from October 1998 to September 1999. Quarterly sampling was conducted at the onset of thermal stratification (late April), in the middle of the stratification period (late July), near the end of the stratification period (early November), and during a winter period of mixis before ice cover (December). Samples were collected at three of the main stations used in the 1998-99 year of study (Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin; see Figure 1).

Samples were collected in the epilimnion, metalimnion, and hypolimnion during the period of thermal stratification and near the top, middle, and bottom of the water column during mixis. Water column profiles of temperature, dissolved oxygen, and other parameters measured with a multiprobe were evaluated in the field to determine depths for metalimnetic samples.

Quarterly sampling continued to be performed in collaboration with MWRA staff at the Deer Island Central Laboratory who provided sample containers and where all grab samples were sent for analysis. Sampling protocol, chain-of-custody documentation, and sample delivery were similar to those established in the 1998-99 year of study. Details of sampling protocol are provided in Water Quality Report: 1999 - Wachusett Reservoir and Watershed (MDC, 2000). Modifications to the quarterly sampling program include only a lower minimum detection limit for total Kjeldahl-nitrogen (reduced to 0.2 mg/L from 0.6 mg/L) and the addition of UV254 absorbance among the parameters to be measured. Measurement of UV absorbance at a wavelength of approximately 254 nanometers serves as a relative assay of the concentrations of organic compounds dissolved in the water.

The nutrient database for Wachusett Reservoir established in the 1998-99 year of monthly sampling and quarterly sampling through 2000 is used as a basis for interpreting data generated in 2001. Results of quarterly nutrient sampling in 2001 document concentrations that generally register within or close to the ranges documented previously (Table 12; see complete quarterly database in Appendix). However, many values of nitrate, silica, total phosphorus, and UV254 absorbance measured in April 2001 were higher than the ranges documented in the historical database. Elevated springtime nutrient concentrations were also observed in 2000 when samples collected in May generally had concentrations that registered among the highest observed all year. This pattern of relatively high nutrient concentrations in spring followed by lower concentrations the remainder of the year (except for hypolimnetic concentrations in summer; see below) reflects the linkage of Wachusett Reservoir to Quabbin Reservoir as described in the paragraphs that follow.

TABLE 12

WACHUSETT RESERVOIR NUTRIENT CONCENTRATIONS

Comparison of Ranges from 1998-00 Database[1] to Results from 2001 Quarterly Sampling

Sampling Station[2]	Ammonia (NH_3; µg/L)		Nitrate (NO_3; µg/L)		Silica (SIO_2; mg/L)	
	1998-00	Quarterly	1998-00	Quarterly	1998-00	Quarterly
Basin North/3417 (E)	<5 - 12	<5 - 7	<5 - 113	23 - 124	1.15 - 2.64	0.82 - 3.02
Basin North/3417 (M)	<5 - 28	6 - 36	<5 - 134	73 - 138	1.41 - 3.13	1.92 - 3.31
Basin North/3417 (H)	<5 - 34	7 - 32	49 - 187	71 - 190	1.84 - 3.92	1.91 - 3.47
Basin South/3412 (E)	<5 - 14	<5 - 8	<5 - 123	26 - 172	1.18 - 2.91	0.88 - 3.84
Basin South/3412 (M)	<5 - 26	<5 - 23	11 - 124	59 - 184	1.40 - 2.87	1.85 - 4.03
Basin South/3412 (H)	<5 - 36	<5 - 33	49 - 173	65 - 224	1.94 - 3.74	1.89 - 4.13
Thomas Basin (E)	<5 - 18	<5 - 8	<5 - 177	27 - 201	1.26 - 5.00	1.13 - 4.98
Thomas Basin (M)	<5 - 18	<5 - 16	<5 - 168	28 - 205	1.29 - 3.73	1.47 - 4.94
Thomas Basin (H)	<5 - 21	<5 - 10	<5 - 176	27 - 236	1.26 - 4.76	1.52 - 4.99

Sampling Station[2]	Total Phosphorus (µg/L)		UV254 (Absorbance/cm)	
	1998-00	Quarterly	Quarterly'00	Quarterly'01
Basin North/3417 (E)	<5 - 13	5 - 12	0.045 - 0.068	0.038 - 0.059
Basin North/3417 (M)	<5 - 11	7 - 17	0.045 - 0.067	0.039 - 0.079
Basin North/3417 (H)	<5 - 12	7 - 14	0.045 - 0.067	0.038 - 0.069
Basin South/3412 (E)	<5 - 12	6 - 16	0.046 - 0.074	0.035 - 0.085
Basin South/3412 (M)	<5 - 11	6 - 22	0.047 - 0.074	0.036 - 0.089
Basin South/3412 (H)	<5 - 10	10 - 37	0.047 - 0.073	0.036 - 0.091
Thomas Basin (E)	<5 - 20	6 - 23	0.069 - 0.136	0.026 - 0.121
Thomas Basin (M)	<5 - 15	7 - 22	0.068 - 0.147	0.026 - 0.135
Thomas Basin (H)	<5 - 22	7 - 20	0.084 - 0.150	0.027 - 0.141

(1) 1998-00 database composed of 1998-99 year of monthly sampling and subsequent quarterly sampling through 2000 except for measurement of UV254 initiated in 2000 quarterly sampling

(2) Water column locations are: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom

Nutrient concentrations in Wachusett Reservoir are influenced by a variety of factors that fluctuate annually including amounts of runoff discharged from the watershed (rain and snowmelt), nutrient loading rates associated with the runoff, and population dynamics of phytoplankton. Overriding these factors however, is the timing and duration of the Quabbin transfer. Water quality within the reservoir basin reflects a dynamic interaction between the influence of the Wachusett watershed and the influence of the Quabbin transfer. The Quabbin transfer is characterized by water of very low nutrient concentrations whereas the influence of the Wachusett watershed is exerted mostly via the discharges of the Quinapoxet and Stillwater Rivers with higher nutrient concentrations.

The interplay between these two influences results in slight shifts in the range of nutrient concentrations from one year to the next. Historically, the peak period of transfer from Quabbin consists of July, August, and September each year, but it has been initiated as early as May and has extended through December or even into the initial months of the next year. In a year with prompt initiation of the Quabbin transfer, such as 1999 when the transfer started on May 3rd, nutrient concentrations will range lower due to the early entry and greater proportion of Quabbin derived water occupying the basin. At the conclusion of 1999, the transfer volume totaled 225 million cubic meters, equivalent to 90 percent of the Wachusett basin volume.

Conversely, in years with delayed or reduced inputs from Quabbin or higher amounts of local precipitation or snowmelt, nutrient concentrations will range higher as discharges from the Quinapoxet and Stillwater Rivers have greater proportional influence. This was evident in 2000 when the Quabbin transfer was not initiated until June 28th and nutrient concentrations were generally highest in samples collected in May of that year. Similarly, in 2001, an exceptionally wet spring intensified nutrient loading from the Quinapoxet and Stillwater Rivers resulting in maximum concentrations recorded on April 26th prior to initiation of the Quabbin transfer on May 16th.

The dominant influence of the Quinapoxet and Stillwater Rivers in the spring of 2001 was especially evident in the form of pronounced horizontal gradients (between sampling locations across the reservoir) in the concentrations of nitrate and silica, in UV254 absorbance, and specific conductance (Table 13). The highest concentrations, absorbance, and conductivity occurred in Thomas Basin closest to the river inlets. Concentrations, absorbance, and conductivity diminished with increasing distance from Thomas Basin due to mixing and dilution in water occupying the main reservoir basin. Water in the main basin is a mixture of approximately equal parts of Quabbin and Wachusett derived water and, therefore, had lower values of these parameters than the river discharges. Thus, April samples collected at Station 3412 (Basin South) had intermediate parameter values and Station 3417 (Basin North), located farthest downgradient from Thomas Basin, had the lowest parameter values (Table 13).

The horizontal gradients became pronounced in the spring of 2001 because of an exceptional amount of precipitation (8 inches in March) and snowmelt runoff. Mean monthly discharge rates of the Quinapoxet and Stillwater Rivers in April were the highest recorded in recent years. The high rates of discharge and correspondingly elevated rates of nutrient delivery caused the lateral gradients in the above parameters to develop and become manifest in the April sample results.

Once the Quabbin transfer was initiated on May 16th the influence of the Quinapoxet and Stillwater Rivers was counteracted and horizontal gradients rapidly dissipated. The onset of thermal stratification and increased biological activity in the water column caused nutrient distribution in the reservoir to revert to previously documented seasonal and vertical patterns that recur annually. These patterns include low epilimnetic concentrations in summer resulting from phytoplankton uptake and higher concentrations accumulating in the hypolimnion due to microbial decomposition of sedimenting organic matter. The annual cycle of nutrient dynamics in Wachusett Reservoir is detailed in Water Quality Report: 1999 - Wachusett Reservoir and Watershed (MDC, 2000).

Table 13

Lateral Gradients in Ranges of Parameter Values Measured on April 26, 2001

Sampling Locations	**Thomas Basin**	**Basin South**	**Basin North**
	>>>>> increasing	distance from river	inlets >>>>>
Nitrate (µg/L)	201 - 236	172 - 192	124 - 138
Silica (mg/L)	4.94 - 4.99	3.84 - 4.13	3.02 - 3.31
UV254 (Absorbance/cm)	0.121 - 0.141	0.085 - 0.091	0.059 - 0.066
Specific Conductance (µS/cm)	121.7 - 136.3	101.2 - 104.2	90.2 - 94.1

Another indication of the divergent influences of the Quabbin transfer and the Wachusett watershed on reservoir water quality is evident later in the year after a summer of sustained transfer. Samples collected in October and December of 2001 document the reverse of springtime horizontal gradients with the concentrations or intensities of certain parameters lowest in Thomas Basin and increasing downgradient. Although not as pronounced as the springtime gradients because of biological and stratification effects on nutrient distribution superimposed during the summer, this reversal of gradients demonstrates that Thomas Basin had been flushed out by the Quabbin transfer while receiving negligible inputs from the Quinapoxet or Stillwater Rivers. During the late summer period of annual minimum river flow and sustained transfer, Thomas Basin was essentially an extension of the Quabbin hypolimnion.

In summary, the relatively elevated concentrations observed in April 2001 reflect high discharge rates from the Quinapoxet and Stillwater Rivers operating prior to the entry of water transferred from Quabbin. Other than the springtime expansion in the ranges of nutrient concentrations discussed above, the seasonal and vertical patterns in the distribution of nutrients in 2001 quarterly samples were comparable to those documented in the historical database (composed of the 1998-99 year of monthly sampling and quarterly sampling through 2000). Future nutrient sampling at Wachusett Reservoir is planned to continue on the quarterly schedule.

3.2.4 ALGAE

Algae samples were collected weekly off the back of the Cosgrove Intake from April 10th through December 26th. The reservoir was covered with ice during January, February, and March, and samples could not be collected safely. Grab samples were taken from the surface and at six, eight, ten, twelve, and fourteen meters using a 2 liter Van Dorn bottle.

A total of 249 discrete samples were collected and analyzed. Half liter samples were concentrated to twelve mL by gravity filtration through sand and silk in Sedgwick-Rafter (SR) funnels. A one mL subsample was placed in a SR counting cell, allowed to settle for fifteen minutes, and then examined at 100X magnification. Algae were identified and counted in three strips comprising approximately ten percent of the subsample. The underside of the coverslip was also scanned to observe any floating bluegreen algae (*Anabaena*) or mobile golden-browns (*Synura*, *Uroglena*, *Dinobryon*).

Only golden-brown genera were identified and counted in samples collected from 6m, 10m, and 12m depths. Detection of mobile golden-brown genera was enhanced by using a 7 - 45X stereozoom dissecting microscope to scan the entire cell prior to a detailed examination at 100X.

Data collected are located in an appendix to this report. They are also accessible as part of an electronic database (Microsoft EXCEL file Algae01.xls) and on paper at the MDC-DWM Water Quality Lab in West Boylston, Massachusetts.

Taxonomic composition, density, and seasonal dynamics of the plankton community throughout Wachusett Reservoir were evaluated through an additional program of quarterly sampling at three sampling stations within the basin. Transparent vinyl tubing (1 inch O.D. x 3/4 inch I.D.) was used to collect depth-integrated samples. The weighted end of the tube was lowered from the surface to a pre-selected depth, the surface end of the tube stoppered to prevent loss of water during tube retrieval, and the tube retrieved with an extracted “core” of the water column. The water in the tube was transferred into a polyethylene bottle (4 liter capacity measuring approximately 30 cm high and 15 cm in diameter) rendering a composite sample of plankton over that depth.

Integrated samples were generally collected to a depth of fifteen meters, which was approximately the depth to the bottom of the metalimnion (and “interflow” stratum; see Section 3.2.2 above) during the period of thermal stratification. Data from water column profiles of dissolved oxygen and hydrogen ion activity (pH) indicate that most photosynthetic activity occurs in the epilimnion and metalimnion which were represented in their entirety in the samples integrated to fifteen meters. This sampling depth was maintained during non-stratified conditions to provide consistency in the data.

Samples were preserved in the field with Lugol’s Solution (3 ml per 1,000 ml of sample according to Standard Methods) and transported to the lab for processing. Prior to microscopic analysis, all samples were concentrated by a process of sedimentation. This entailed keeping the sample bottles undisturbed for a least one week to allow the organisms to settle to the bottom and then decanting the overlying supernatant in each bottle with a peristaltic pump. The one week minimum sedimentation period surpasses the EPA (1973) guideline of 4 hours per 1 cm depth of sample bottle. Samples were concentrated generally between 5% and 15% of their original volume by this process. Final results reported for each sample will incorporate the appropriate correction factor.

In addition to the quantitative samples of plankton collected with the integrated tube sampler, a net was used to collect qualitative samples of the larger forms of plankton. A plankton net of 35 micron mesh was manipulated vertically in the water column at Station 3417 (Basin North) in conjunction with monthly collection of integrated tube samples. The net filters and concentrates plankton from an unknown quantity of water and cannot provide estimates of density, but does enable the relative abundances of the larger forms to be determined.

Microscopic analysis of plankton samples was performed with a compound microscope capable of magnification from 40 to 1,000 times and using phase-contrast illumination. Plankton taxa in the integrated samples were enumerated using a Sedgewick-Rafter (S-R) Cell which enables plankton densities to be quantified. Each concentrated sample was inverted a few times to homogenize the sample and then 1 ml of the sample was withdrawn with a pipette and placed into the S-R Cell. Approximately 15 minutes were allowed for the plankton to settle to the bottom of the S-R Cell before enumeration. Plankton were enumerated in a total of 10 fields described by an ocular micrometer. At 200X magnification, the ocular field measures 0.3136 square millimeters in area (previously calibrated with a stage micrometer) and the fields were selected for viewing at approximately 0.5 cm intervals across the length of the S-R Cell.

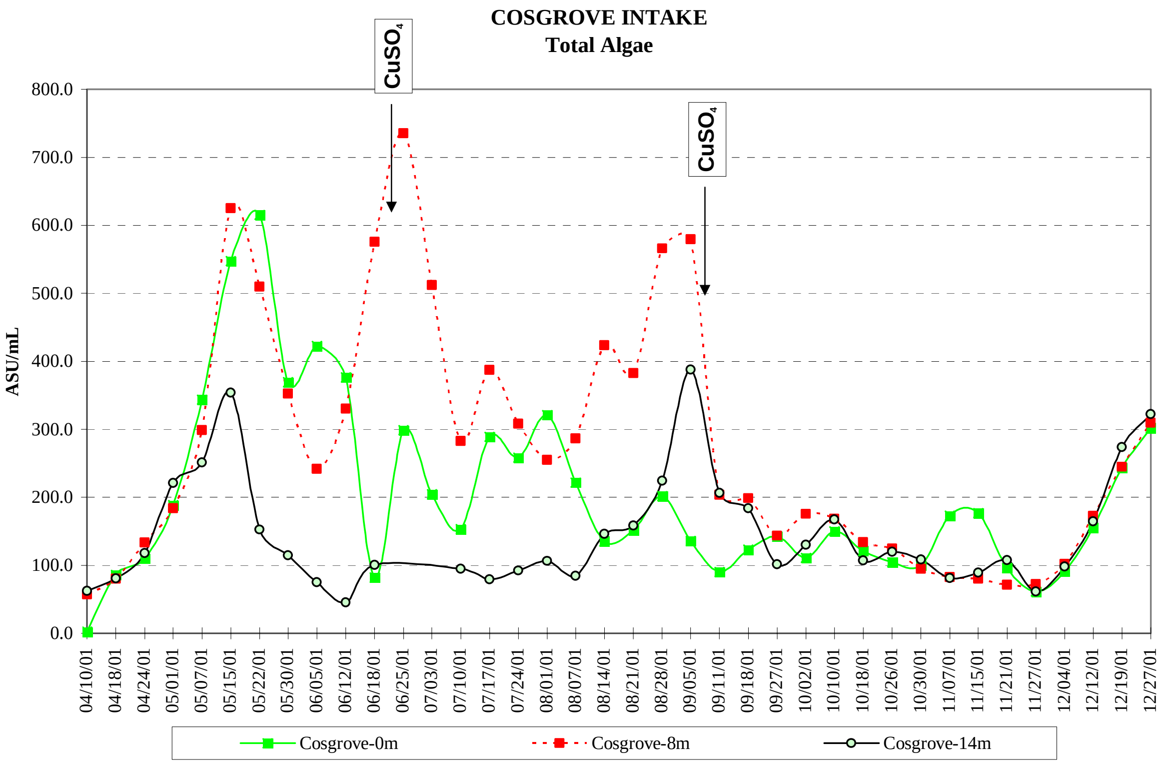
Plankton densities were expressed as Areal Standard Units (ASUs; equivalent to 400 square microns). The area of each specimen viewed in each counting field was estimated using the ocular micrometer (the ocular field was divided into a 10 by 10 grid, each square in the grid having an area of 3,136 square microns or 7.84 ASUs at 200X magnification). In the case of taxa which form gelatinous envelopes or sheaths, such as *Microcystis*, the area of the envelope was included in the estimate for that specimen. The areal extent of certain colonial taxa, such as the diatoms *Asterionella* and *Tabellaria*, was estimated by measuring the dimensions of one cell and multiplying by the number of cells in the colony. Cell fragments or structures lacking protoplasm, including lorica of *Dinobryon*, diatom frustules, and thecae of dinoflagellates were not counted.

Phytoplankton and zooplankton were generally identified to genus, although copepods were identified only to suborder (Calanoida or Cyclopoida). An effort was made to identify dominant forms of plankton to species. Analysis of preserved plankton samples collected quarterly is still in progress and will be reported in a later publication.

Algal populations at the Cosgrove Intake in 2001 were unmonitored during the first three months of the year due to ice cover. Very low total algae concentrations were recorded in early April immediately after ice-out (Figure 12). Concentrations rapidly increased at all depths through April and half of May, but declined at the end of the latter month. Total concentrations continued to decline at the surface and at fourteen meters following an MWRA application of copper sulfate in mid June (responding to increases in *Anabaena* and *Dinobryon*), but increased at eight meters to an annual maximum of 735 ASU/mL as the result of a bloom of centric diatoms that was initially unaffected by the treatment.

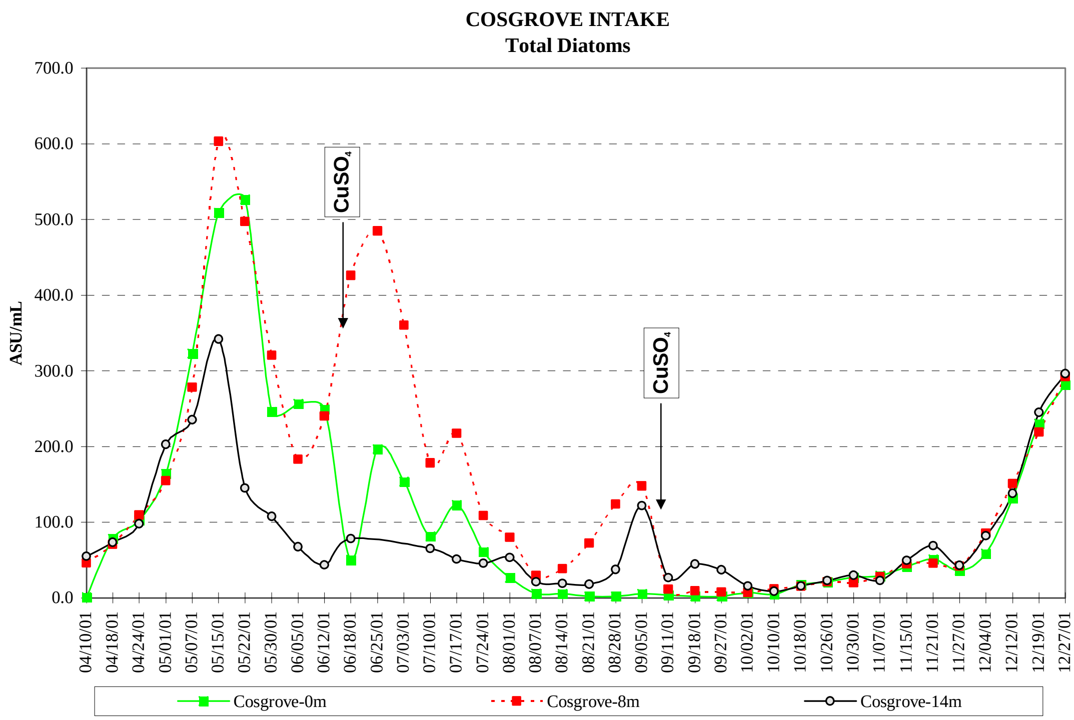
Total concentrations declined at the end of June to about 300 ASU/mL (100 ASU/mL at 14m) and then increased again in August. Numbers declined sharply following a second application of copper sulfate by the MWRA in early September and remained low until December, when normal increases in diatoms elevated total algae concentrations to just over 300 ASU/mL (Figure 12).

Figure 12



Spring and early summer populations were comprised primarily (50-98%) of diatoms. *Asterionella* was often the dominant genus (up to 59% of total algae) early, but centric diatoms (58% of the total on July 10th) and *Rhizosolenia* (50% on June 5th) were also an important component of the algal community. Diatoms remained dominant for a longer period at depth than at the surface. Populations at all depths declined after a May maximum and remained low except for a bloom of centric diatoms at eight meters in June and an increase in Asterionella at depth at the end of the summer (see Figure 13). Total diatom concentrations remained low but began to slowly increase through the fall and then increased rapidly in December. More than 50% of the algal community was made up of diatoms by late November; over 90% were diatoms by the end of the year. The predominant genus (75% of the total) was again *Asterionella*.

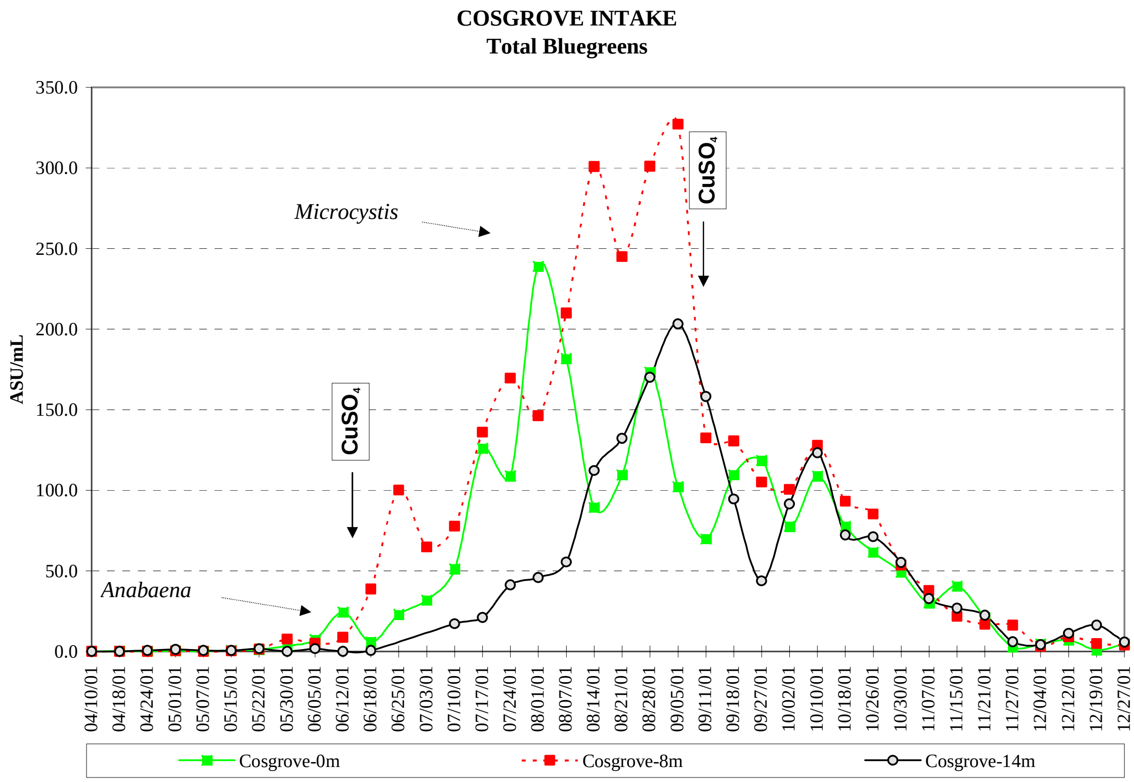
Figure 13



Bluegreen algae were present at very low concentrations until the beginning of June, with total numbers never exceeding 10 ASU/mL. Numbers rose at the surface in mid June as *Anabaena* began to increase, and then rose sharply in late June and through the summer due to a bloom comprised primarily of the colonial alga *Microcystis* (Figure 14). Samples collected from eight meters contained concentrations of total bluegreens as high as 327 ASU/mL, while samples from the surface and from fourteen meters both reached concentrations above 200 ASU/mL. The northern end of the reservoir was treated with copper sulfate in mid June to keep *Anabaena* concentrations from increasing further and to control elevated concentrations of golden-browns. This quick response to increases in concentrations appears to have suppressed the annual bloom of *Anabaena* once again, because only very low concentrations of this problematic genus have been noted during the past two years.

Total bluegreens were present at greater than normal concentrations throughout the summer, continuing a trend reported over the past few years. *Microcystis* continues to make up a significant proportion of the summer bluegreen population. A second treatment with copper sulfate was done in early September to reduce concentrations of Dinobryon and Synura and to avoid the development of taste and odor problems. Bluegreen algae concentrations at all depths were significantly reduced and continued to decline for the remainder of the year (Figure 14).

Figure 14

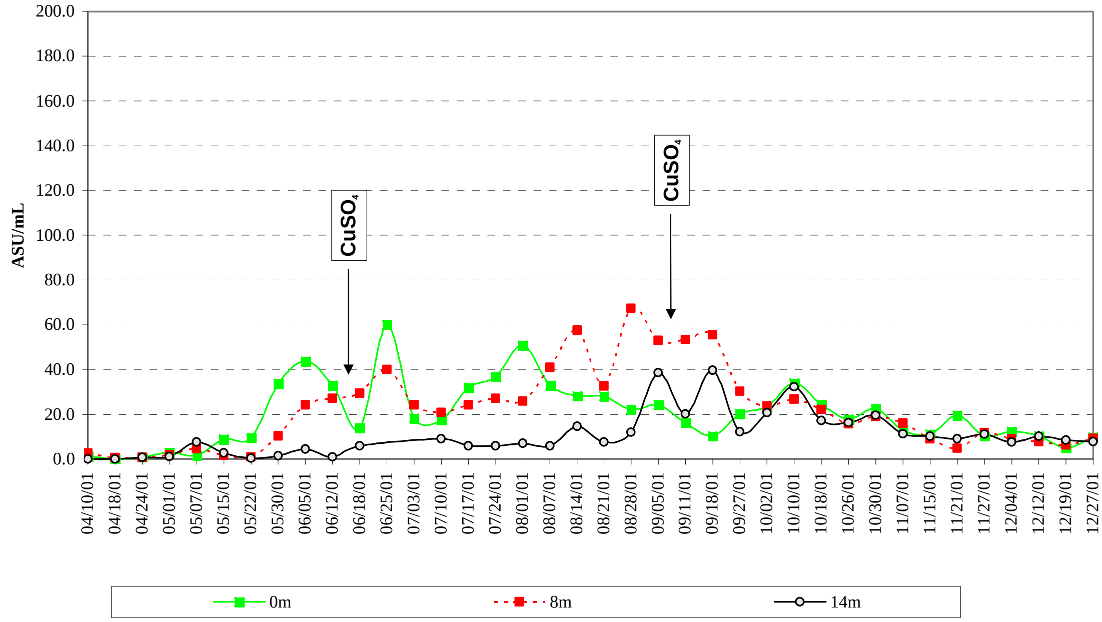


The increasing presence of bluegreen algae during the summer is a disturbing trend. Bluegreens have been noted each summer over the past thirteen years, but concentrations generally have been low, with the exception of an annual *Anabaena* bloom. Total bluegreen algae concentrations (excluding the short bloom period for *Anabaena* in June or July) have never exceeded 100 ASU/mL prior to 1999, with summer concentrations generally between 50 and 80 ASU/mL. Total bluegreen concentrations exceeded 150 ASU/mL in 1999 and again in 2000, and exceeded 300 ASU/mL in 2001. The colonial alga *Microcystis*, previously rare to uncommon at Wachusett, now is the most commonly found genus during the summer and fall. This could indicate the beginning of a decline in water quality and the potential for more frequent taste and odor episodes.

Green algae were present at all depths throughout the year, with highest concentrations (50 – 68 ASU/mL) noted at the surface and at eight meters from June through September. Concentrations were below 20 ASU/mL until the end of May and from mid October to the end of the year (Figure 15). Green algae comprised 10% – 28 % of the total algal population through the summer, with smaller amounts present during the remainder of the year. Concentrations at fourteen meters were almost always lower than at the surface or at 8m.

Figure 15

COSGROVE INTAKE
Total Greens



Golden-brown algae were present in low concentrations at all depths until mid May. A bloom of *Dinobryon* in the top eight meters took place in May and June, with total golden-brown concentrations increasing from less than 40 ASU/mL to more than 250 ASU/mL (Figure 16). Numbers declined following an application of copper sulfate in mid June, although concentrations at six and eight meters did increase initially due to the presence of *Chrysosphaerella*. Concentrations increased at all depths during August. *Dinobryon* was again the dominant genus, although *Synura* was also present in excess of the 20 ASU/mL treatment threshold, and the MWRA added copper sulfate to the reservoir in early September. Golden-brown concentrations dropped sharply and remained low (<25 ASU/mL) for the remainder of the year except for two brief periods in October and November when *Uroglena* colonies became more common and total golden-brown concentrations were between 50 and 100 ASU/mL.

Synura concentrations were not as stable or low as they had been during the previous year (Figure 17). Concentrations exceeded 10 ASU/mL at six and eight meters in the middle of June, but then declined well in advance of the copper sulfate treatment one month later. Concentrations rose again during August and exceeded 20 ASU/mL at ten meters in early September. The MWRA added copper sulfate and Synura was rarely detected at any depth for the rest of the year. *Synura* was expected to be a problem in 2001 as diatom concentrations in the spring never approached 1000 ASU/mL. Data from the past seven years seem to clearly show a link between low spring diatom concentrations and significant autumn increases of *Synura*. Competition for silica seems to play an important role in the relationship between these two groups.

Figure 16

COSGROVE INTAKE
Total Golden-Browns

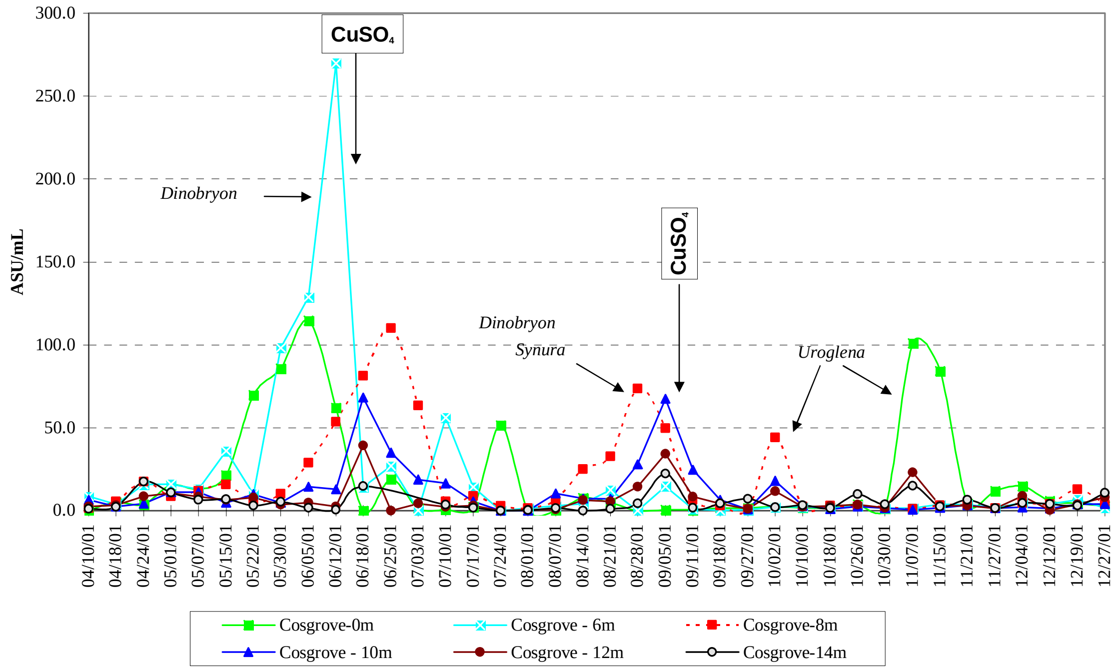
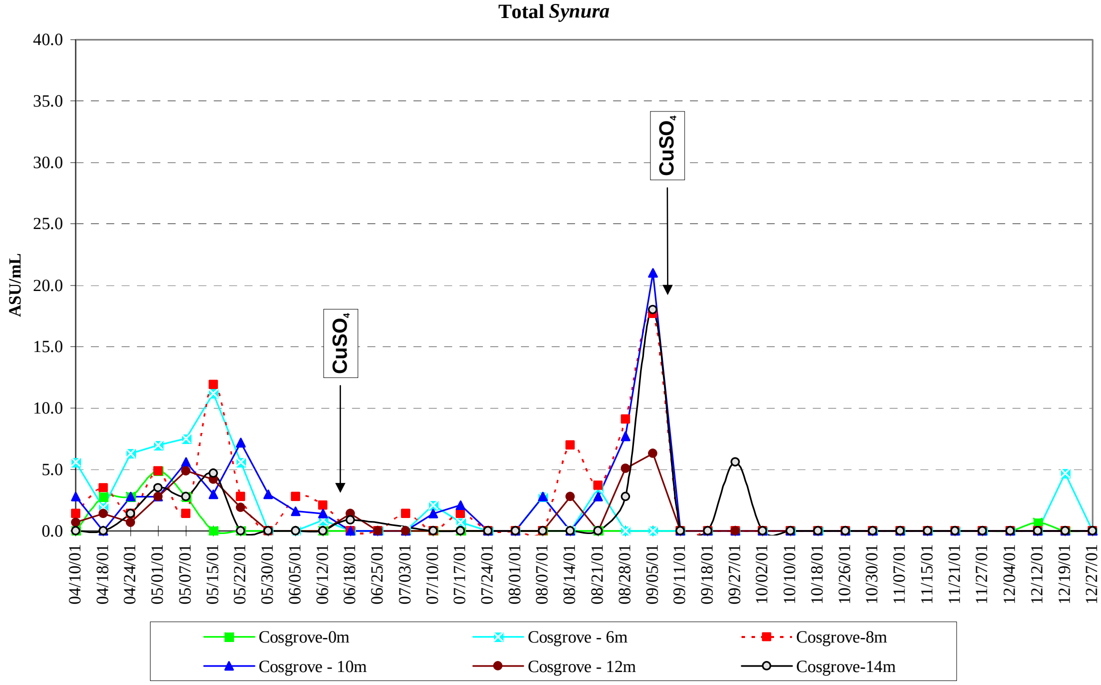


Figure 17

COSGROVE INTAKE
Total *Synura*



4.0 SAMPLING PLAN

The Wachusett watershed sampling program for 2002 will include special studies, enforcement actions, incident response, and routine sampling and analysis, and the routine sampling program will again attempt to focus on the effects of storm events on tributary and reservoir water quality. The program was designed to protect public health, identify current and potential threats to water quality, and further our understanding of the reservoir and its tributaries.

Fecal coliform, total coliform, and conductivity are measured weekly at twenty stations on fifteen tributaries. Quarterly nutrient samples are collected from eleven tributary stations with available flow data. The stations sampled include all significant tributaries that discharge directly to the reservoir. A separate stormwater sampling program including all routinely sampled tributaries will also be part of the regular sampling program if staff and funding levels allow to help quantify bacterial loading to the reservoir from storm events. Tributary sampling will take place immediately following rain events (first flush) and then all stations will be resampled after 24 and 48 hours to see how long elevated fecal coliform concentrations persist after a storm. Precipitation amounts, groundwater levels, and stream flows will all be carefully documented and compared to bacteria numbers to attempt to further refine our understanding of the causes of elevated fecal coliform levels in Wachusett tributaries.

Fecal and total coliform bacteria samples are collected daily four days per week at the Cosgrove Intake and from the Route 12 Bridge at the upper end of the reservoir. Monthly temperature, dissolved oxygen, pH, and conductivity profiles are taken at three reservoir stations (3417-Basin North, 3412-Basin South, and Thomas Basin) during ice-free periods using a Hydrolab H20 Sonde Unit and a Surveyor III data logger. More frequent profiles will be collected when necessary to document changing conditions in the reservoir. Algae samples are collected once or twice a week at six depths from the Cosgrove Intake and quarterly from three additional reservoir stations. Samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, and silica will be collected quarterly from the three reservoir stations.

The movement of water and contaminants through the reservoir, especially during times when water is being transferred to Wachusett Reservoir from Quabbin Reservoir, has become the focus of significant interest. Sampling of the reservoir surface will continue on a regular basis. Monthly, biweekly, or weekly transect sampling will be done when feasible to help further understand the effect of water movement on fecal coliform levels throughout the reservoir. Some sampling at different depths will also be done.

The *Giardia* and *Cryptosporidium* sampling program was originally designed to focus on the development of baseline data in the Wachusett watershed. Samples were collected for two years at two stations on the major tributaries to the Wachusett Reservoir (the Quinapoxet and Stillwater Rivers). Samples were also collected for two years from two smaller tributaries surrounded by residential development (Gates Brook) and by wildlife habitat (French Brook). A study of the movement of pathogens during storm events was initiated by UMASS in 2001 with funding from the American Water Works Association Research Foundation and the cooperation of the MDC Division of Watershed Management. The study is designed to look at different land uses (agriculture, residential, forest) and determine how best to monitor pathogens and their movement through the watershed during both wet and dry conditions throughout the year. This information will be used to optimize future sampling programs and to more accurately predict potential public health problems. Continued work on the study is planned through 2003.

Macroinvertebrate samples were collected during the spring of 2001 from twenty-three stations on twenty tributaries to help detect impacts of intermittent pollution events that might otherwise be missed by routine sampling programs. Additional samples were collected in the summer and fall to investigate seasonal variation in Wachusett tributaries. An attempt will be made to identify all samples during 2002. Population information developed from these samples will be compared with historic data collected over the last twelve years.

Sampling of the Pinecroft area drainage basin will continue in order to evaluate the impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling has established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small subbasin at the headwaters of Gates Brook prior to sewer construction. The same has been done for two additional sampling locations, one in a pristine forested watershed and one at an agricultural operation, in order to enable the Division to compare and contrast the three land uses. The multi-year study will continue during 2002 as sewer hookups are completed with weekly bacteria samples and monthly nutrient samples at three stations to monitor water quality after sewers are in the ground and to compare water quality in areas with different land uses. Additional storm sampling will also take place when feasible, with focus on collection of data during different seasonal conditions.